The University of Alberta
Printing Department
Edmonton, Alberta

THE UNIVERSITY OF ALBERTA

THE COMPARATIVE MICROMORPHOLOGY OF ARGILLIC HORIZONS OF THREE GRAY LUVISOLS

by

(C) ROBERT PETER INNES, B.Sc.

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH

IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE

OF MASTER OF SCIENCE

DEPARTMENT OF SOIL SCIENCE

EDMONTON, ALBERTA

FALL, 1971

UNIVERSITY OF ALBERTA

FACULTY OF GRADUATE STUDIES AND RESEARCH

The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research for acceptance, a thesis entitled "The Comparative Micromorphology of Argillic Horizons of Three Gray Luvisols" submitted by Robert Peter Innes, B.Sc., in partial fulfilment of the requirements for the degree of Master of Science.

Date September 24, 1971

ABSTRACT

The objective of the study was to investigate on a comparative basis similarities and differences existing in Bt horizons of three soils of the Gray Wooded Great Group in the System of Soil Classification for Canada.

Pedons investigated at Site 1 (near Hinton, Alberta) represented soils developed in the Foothills region of the province from Cordilleran till. Pedons at Site 2 (near Nojack, Alberta) represented soils developed in the Plains region of the province from Continental till. Pedons at Site 3, located near Whitecourt in the Highland region of Alberta represented soils developed from Continental till similar to Site 2. The three regions have a cold, subhumid climate and vegetation characteristic of the Boreal-Cordilleran Transition phytogeographic region.

Five pedons at each site were characterized macromorphologically and revealed differences in profile horizonation, color, structure, texture, consistence, rooting arrangement and pore space among the three sites and to a lesser extent within site. All pedons were sampled by horizon for physical and chemical analysis with additional samples taken from Bt horizons for micromorphological analysis.

Physical analyses showed (a) an increasing bulk density with increasing depth at the three sites, (b) a greater coarse fragment (greater than 2mm) content in pedons at Site 1 than in the other two sites, (c) pedons at Site 1 had a lower bulk density in all horizons sampled than similar horizons at the other two sites, (d) the least amount of total clay in the pedons occurred at Site 1 and the most at Site 3 with an opposite relationship for the sand size fraction, (e) the fine clay to

coarse clay ratio increased with depth in the pedons to a maximum in the lower Bt's at Sites 2 and 3 and decreased with increasing depth, and (f) the least values for the fine clay to coarse clay ratios occurred at Site 1 and the greatest at Site 3.

pH was lowest and had narrowest ranges in horizons of maximum clay content, had acidic to neutral values in the parent material, and was inversely proportional to exchangeable acidity. Summation of exchangeable cations was closely related to fine clay content throughout the solum. Clays from pedons were similar in mineralogy between Sites 2 and 3 with greater amounts of amorphous clay size particles at Site 1 and lesser amounts of clay minerals.

Comparative micromorphological examination of Bt horizons of pedons from the three sites was conducted in three ways: (1) Descriptive micromorphology, employing terminology defined by Brewer, was used to characterize thin sections of segments of Bt horizons with reference to color, structure of aggregates, type and arrangement of skeletal members, type and arrangement of voids, and presence type and arrangement of cutanic features. Comparison of plasmic fabrics of Bt horizons gave some insight into possible differences in processes of pedogenesis within sites and among sites. (2) Modal analysis based on thirteen variables and 400 counts per thin section quantitatively evaluated segments of Bt horizons at each site, Bt horizons within pedons at Sites 2 and 3, pedons by similar horizons within sites, and Bt horizons among sites. Modal analysis revealed (a) a fairly constant mineral fraction with increasing depth at all three sites, (b) an increasing rock fragment content with increasing depth, (c) the proportion of total cutans had

the same trend as fine clay content, and (d) organic matter represented a very small proportion of the Bt horizons. (3) Scanning electron micrographs of natural peds from Bt horizons of pedons at the three sites were used on a comparative basis within site and among sites for topographic features of surfaces. Micrographs (a) confirmed orientation of clay size particles in cutans observed by optical microscopy, (b) revealed large differences in surface topography between the Bt horizon at Site 1 and the other two sites, and (c) revealed differences between cutanic surfaces and slickensides.

ACKNOWLEDGEMENTS

Sincere appreciation is extended to Dr. D.J. Pluth, Associate Professor of Soil Science, for his encouragement and guidance during the course of the project, for his assistance in the selection and sampling of Site 3, and for his patience and assistance in the preparation and review of the manuscript.

Appreciation is extended to Dr. D.G.W. Smith, Department of Geology, for his patience and assistance in experiments with the Scanning Electron Microprobe. Further thanks are extended to Mr. J.W. Bloor and Dr. J.E. Gillott, Department of Civil Engineering, University of Calgary, for their advice and assistance with the Scanning Electron Microscope.

Special thanks are extended to Dr. J. Dumanski, Pedologist, Soils Division, Research Council of Alberta, for his assistance in the selection, classification and sampling of Site 1 and the multitude of helpful suggestions concerning micromorphology, and to Mr. A. Twardy, Pedologist, Research Council of Alberta, for assistance in selection, classification and sampling of Site 2. Special thanks are also extended to Mr. J. Hermans, Graduate Student, Department of Soil Science, for the characterization of vegetation.

Appreciation for technical assistance is expressed to Mr. J. Beres for assistance in preparation of thin sections, and to Mrs. Helen Colwell for some of the chemical analyses. In addition I am most grateful to Miss Linda Fraser for the excellent secretarial work in typing and correcting this manuscript, to Mr. D. Gould for

his patience and assistance in reviewing and collating the thesis, and to members of the examining committee.

Special recognition is extended to my wife, Maureen, for long years of encouragement and patience.

TABLE OF CONTENTS

	Page
INTRODUCTION	1
Surficial Geology	2
Site 1	2
Site 2	2
Site 3	3
Climate	4
Vegetation	5
LITERATURE REVIEW	13
Micromorphology	14
Fabric of Bt Horizons	18
MATERIALS AND METHODS	24
Sampling	24
Physical Analyses	28
(a) Bulk Density	28
(b) Moisture Content	28
(c) Particle Size Analysis	28
Chemical Analyses	29
(a) Soil Reaction	29
(b) Total Carbon	29
(c) Total Nitrogen	29
(d) Exchange Acidity	29
(e) Exchangeable Cations	29
X-ray Diffraction	30

Page

Micromorphological Analyses 30

Modal Analyses. 31

Scanning Electron Microscopy 34

RESULTS AND DISCUSSION

I CHARACTERIZATION 37

A. Macromorphology 37

Site 1 37

Site 2 40

Site 3 45

B. Laboratory Studies 49

1. Physical Analyses 49

(a) Natural Moisture Content and Bulk Density . 49

(b) Particle Size Analysis 52

2. Chemical Analyses 58

(a) Soil Reaction 58

(b) Carbon and Nitrogen 60

(c) Sums of Exchangeable Cations 60

(d) Exchangeable Cations 63

3. X-ray Diffraction 69

II DESCRIPTIVE MICROMORPHOLOGY 85

Site 1 85

Site 2 98

Site 3 107

III MODAL ANALYSIS 118

IV SCANNING ELECTRON MICROSCOPY 132

Page

V SOIL CLASSIFICATION 162

SUMMARY AND CONCLUSIONS 164

LITERATURE CITED 167

APPENDIX A1

A. Pedon Macromorphology A1

B. Physical and Chemical Pedon Characterization B1

C. Modal Analysis C1

LIST OF TABLES

Table		Page
1	SPECIES LIST AND OCULAR COVER ESTIMATES	10
2	MEAN VALUES, STANDARD DEVIATIONS, AND 95% CONFIDENCE LIMITS FOR MOISTURE CONTENT, BULK DENSITY AND CORRECTED BULK DENSITY FOR SITES 1, 2, & 3	51
3	MEAN VALUES FOR PARTICLE SIZE DISTRIBUTION, SILT TO CLAY RATIO, AND FINE CLAY TO COARSE CLAY RATIO WITH MEAN DEVIATIONS IN PEDONS AT SITE 1	53
4	MEAN VALUES FOR PARTICLE SIZE DISTRIBUTION, SILT TO CLAY RATIO, AND FINE CLAY TO COARSE CLAY RATIO WITH MEAN DEVIATIONS IN PEDONS AT SITE 2	54
5	MEAN VALUES FOR PARTICLE SIZE DISTRIBUTION, SILT TO CLAY RATIO, AND FINE CLAY TO COARSE CLAY RATIO WITH MEAN DEVIATIONS IN PEDONS AT SITE 3	55
6	MEAN VALUES AND MEAN DEVIATIONS FOR TOTAL CARBON, NITROGEN AND C/N RATIOS FOR PEDONS SAMPLED AT THREE SITES	61
7	EXCHANGEABLE CATIONS IN SELECTED PEDONS AT THREE SITES	64
8	CRITERIA FOR X-RAY IDENTIFICATION OF CLAY MINERALS	70
9	DEFINITIONS OF SELECTED MICROMORPHOLOGICAL TERMS AS ELUCIDATED BY BREWER (1964a, and 1964b)	86
10	MEAN VALUES AND STANDARD DEVIATIONS OF MICROMORPHOLOGICAL CONSTITUENTS OF Bt HORIZONS FOR PEDONS AT SITE 1 ON A PERCENTAGE BASIS	119
11	MEAN VALUES AND STANDARD DEVIATIONS OF MICROMORPHOLOGICAL CONSTITUENTS OF Bt HORIZONS FOR PEDONS AT SITE 2 ON A PERCENTAGE BASIS	120
12	MEAN VALUES AND STANDARD DEVIATIONS OF MICROMORPHOLOGICAL CONSTITUENTS OF Bt HORIZONS FOR PEDONS AT SITE 3 ON A PERCENTAGE BASIS	122
13	MEANS, STANDARD DEVIATIONS, AND COEFFICIENTS OF VARIATION FOR TOTAL SKELETON, TOTAL VOIDS, TOTAL PLASMA, AND TOTAL CUTANS FOR Bt HORIZONS AT SITE 1 ON A PERCENTAGE BASIS	124

Table | Page

14 MEANS, STANDARD DEVIATIONS, AND COEFFICIENTS OF VARIATION FOR TOTAL SKELETON, TOTAL VOIDS, TOTAL PLASMA, AND TOTAL CUTANS FOR Bt HORIZONS AT SITE 2 ON A PERCENTAGE BASIS 125

15 MEANS, STANDARD DEVIATIONS, AND COEFFICIENTS OF VARIATION FOR TOTAL SKELETON, TOTAL VOIDS, TOTAL PLASMA, AND TOTAL CUTANS FOR Bt HORIZONS AT SITE 3 ON A PERCENTAGE BASIS 126

LIST OF FIGURES

Figure		Page
1	MEAN DAILY TEMPERATURE (°F) OVER A ONE YEAR PERIOD	6
2	MONTHLY RAINFALL (INCHES) OVER A ONE YEAR PERIOD MONTHLY SNOWFALL (INCHES) OVER A ONE YEAR PERIOD	7
3	LOCATION OF PEDONS SAMPLED AT SITE 1 (S9-TP49-R25-W5)	25
4	LOCATION OF PEDONS SAMPLED AT SITE 2 (NE5-TP52-R13-W5)	26
5	LOCATION OF PEDONS SAMPLED AT SITE 3 (SW3-TP61-R13-W5)	27
6	MEAN VALUES AND MEAN DEVIATIONS OF COARSE AND FINE CLAY PARTICLE SIZES IN PEDONS AT THREE SAMPLING SITES	57
7	RANGE OF pH VALUES BY HORIZON IN PEDONS SAMPLED AT SITES 1, 2 AND 3	59
8	MEAN VALUES AND MEAN DEVIATIONS FOR THE SUM OF EXCHANGEABLE CATIONS IN PEDONS AT SITES 1, 2 AND 3	62
9	MEAN VALUES AND MEAN DEVIATIONS FOR EXCHANGEABLE CATIONS AS A PERCENTAGE OF THE SUM OF EXCHANGEABLE CATIONS AT SITE 1	66
10	MEAN VALUES AND MEAN DEVIATIONS FOR EXCHANGEABLE CATIONS AS A PERCENTAGE OF THE SUM OF EXCHANGEABLE CATIONS AT SITE 2	67
11	MEAN VALUES AND MEAN DEVIATIONS FOR EXCHANGEABLE CATIONS AS A PERCENTAGE OF THE SUM OF EXCHANGEABLE CATIONS AT SITE 3	68
12	X-ray diffractograms of <2μ clays from pedons at Site 1 under Mg saturated - air dry treatments	73
13	X-ray diffractograms of <2μ clays from pedons at Site 1 under Mg saturated - glycolated treatments	74
14	X-ray diffractograms of <2μ clays from pedons at Site 1 under K saturated treatments dried at 105°C	75
15	X-ray diffractograms of <2μ clays from pedons at Site 1 under K saturated treatments heated to 550°C	76

Figure | Page

16 X-ray diffractograms of <2μ clays from pedons at Site 2 under Mg saturated - air dry treatments 77

17 X-ray diffractograms of <2μ clays from pedons at Site 2 under Mg saturated - glycolated treatments 78

18 X-ray diffractograms of <2μ clays from pedons at Site 2 under K saturated treatments dried at 105°C 79

19 X-ray diffractograms of <2μ clays from pedons at Site 2 under K saturated treatments heated to 550°C 80

20 X-ray diffractograms of <2μ clays from pedons at Site 3 under Mg saturated - air dry treatments 81

21 X-ray diffractograms of <2μ clays from pedons at Site 3 under Mg saturated - glycolated treatments 82

22 X-ray diffractograms of <2μ clays from pedons at Site 3 under K saturated treatments dried at 105°C 83

23 X-ray diffractograms of <2μ clays from pedons at Site 3 under K saturated treatments heated to 550°C 84

LIST OF PLATES

Plate		Page
1.1	Photomicrograph of skelsepic plasmic fabric from upper portion of Bt horizon showing strongly expressed skeletal cutans (crossed polarizers). (Site 1, Pedon 5, Upper portion Bt).	93
1.2	Photomicrograph of vo-skelsepic plasmic fabric showing skeleton and vugh argillans (crossed polarizers). (Site 1, Pedon 2, Upper portion Bt)	93
2.1	Photomicrograph of iron and organic stained plasmic materials observed in Bt_1 and Bt_2 horizons at Site 2 (partially crossed polarizers) (Site 2, Pedon 5, Bt_2 upper)	99
2.2	Photomicrograph of ortho and metavughs observed in Bt_1 and Bt_2 horizons (crossed polarizers) (Site 2, Pedon 1, Bt_1 upper). .	99
3.1	Photomicrograph of skew plane argillans with associated plasmic separations in the form of oriented striations (crossed polarizers) (Site 2, Pedon 5, Bt_1 upper)	102
3.2	Photomicrograph of a plasma separation (slickenside). Note abundance of striated clays with parallel orientation (crossed polarizers). (Site 2, Pedon 5, Bt_2 upper)	102
4.1	Photomicrograph of regular packing arrangement of very well defined, subrounded blocky primary peds (crossed polarizers) (Site 3, Pedon 2, Bt_1 upper)	108
4.2	Photomicrograph depicting large primary peds as compared to Plate 4.1. Note meta-skew-plane traversing photomicrograph (crossed polarizers) (Site 3, Pedon 1, Bt_2 bottom)	108
5.1	Photomicrograph of ortho- and metavughs (crossed polarizers) (Site 3, Pedon 1, Bt_2 bottom).	112
5.2	Photomicrograph of sedimentary rock fragment displaying fractures and stained areas. Note thin embedded grain cutans (crossed polarizers) (Site 3, Pedon 2, Bt_2 upper). .	112
6.1	Photomicrograph of argillasepic plasmic fabric in lower portion of Bt_3 horizon of Pedon 5 at Site 3 (crossed polarizers).	114
7.1	Natural ped surface. Magnification 650x. (Site 1, Pedon 4, Bt Horizon)	135
7.2	Central section of Plate 7.1 (natural ped surface) Magnification 2.6K. (Site 1, Pedon 4, Bt Horizon)	135
8.1	Surface material at edge of crack in ped. Magnification 2.4K. (Site 1, Pedon 4, Bt Horizon)	136

Plate		Page
9.1	Coated skeleton grain with uplifted skeletal cutan. Magnification 700x. (Site 1, Pedon 4, Bt Horizon)	138
9.2	Left center section of Plate 9.1, uplifted skeletal cutan. Magnification 2.8K. (Site 1, Pedon 4, Bt Horizon) . .	138
10.1	Portion of a root penetrating ped surface and extending to the interior. Magnification 135x. (Site 1, Pedon 4, Bt Horizon)	140
10.2	Edge of root hole in Plate 10.1 with smooth planar surface (lower right) and random distribution of plasma. Magnification 1.35K. (Site 1, Pedon 4, Bt Horizon)	140
11.1	Failure plane in ped caused by root complex. Magnification 130x. (Site 1, Pedon 4, Bt Horizon)	141
11.2	Section of Plate 11.1 showing arrangement of plasma on failure plane. Magnification 6.5K. (Site 1, Pedon 4, Bt Horizon)	141
12.1	Tubular pore in ped. Magnification 280x. (Site 2, Pedon 5, Bt_1 Horizon)	143
12.2	Edge of tubular pore in upper right of Plate 12.1. Magnification 1.4K. (Site 2, Pedon 5, Bt_1 Horizon)	143
13.1	Wall of tubular pore in Plate 12.1. Magnification 2.8K. (Site 2, Pedon 5, Bt_1 Horizon).	144
14.1	Failure plane in ped caused by root penetration. Magnification 67x. (Site 2, Pedon 5, Bt_1 Horizon)	146
14.2	Central section of Plate 14.1. Root fragment in lower right. Magnification 270x. (Site 2, Pedon 5, Bt_1 Horizon) . .	146
15.1	Center section of Plate 14.2 showing oriented clays in root channel. Magnification 6.7K. (Site 1, Pedon 5, Bt_1 Horizon)	147
16.1	Planar crack normal to cutanic surface on ped. Magnification 620x. (Site 2, Pedon 5, Bt_1 Horizon)	149
16.2	Edge of crack in Plate 16.1 at upper surface. Magnification 12.5K. (Site 2, Pedon 5, Bt_1 Horizon)	149
17.1	Skew plane argillan on ped (photographed normal to surface). Magnification 1.4K. (Site 2, Pedon 5, Bt_1 Horizon)	151

Plate		Page
17.2	Central section of Plate 17.1. (Photographed at an angle approximately 30° from the normal). Magnification 7K. (Site 2, Pedon 5, Bt_1 Horizon)	151
18.1	Slickenside on ped (photographed 45° from normal). Magnification 2.7K. (Site 2, Pedon 5, Bt_2 Horizon)	153
18.2	Edge of slickenside in Plate 18.1. Magnification 2.4K. (Site 2, Pedon 5, Bt_2 Horizon)	153
19.1	Plane argillan on ped surface (photographed 45° from normal). Magnification 2.7K. (Site 2, Pedon 5, Bt_2 Horizon)	155
19.2	Inped plasma on artificial fracture surface of plane in Plate 19.1. Magnification 2.4K. (Site 2, Pedon 5, Bt_2 Horizon)	155
20.1	Face of disintegrating ped (photographed 45° from normal). Magnification 2.6K. (Site 3, Pedon 1, Bt_1 Horizon)	157
21.1	Fracture face of ped fragment (natural fracture). Magnification 1.2K. (Site 3, Pedon 1, Bt_1 Horizon)	159
21.2	Skeleton grain protruding from plasma in disintegrating ped (Plate 20.1). Magnification 250x. (Site 3, Pedon 1, Bt_1 Horizon)	159
22.1	Plane argillan (photographed from the normal). Magnification 7K. (Site 3, Pedon 1, Bt_3 Horizon)	161
22.2	Ped surface without cutans. Magnification 1.6K. (Site 3, Pedon 1, Bt_3 Horizon)	161

INTRODUCTION

Soils possessing argillic horizons have been studied and characterized by numerous pedologists. One soil possessing this characteristic is the Gray Wooded Great Group in the System of Soil Classification for Canada. These soils have developed on a variety of parent materials under different physiographic conditions. The development of Gray Wooded soils is believed to result from leaching of parent materials by acidic decomposition products from forest vegetation. Results of numerous studies indicate a characteristic morphology for such soil profiles.

The study was undertaken in three phases. The objective of the first phase was to investigate soils of three sites, two with similar parent materials, for purposes of macromorphological pedon characterization. The second phase of the study consisted of physical and chemical analyses for the purpose of more detailed pedon characterization. The objective of the third phase was to investigate on a microscopic basis the arrangement of soil constituents in the Bt horizons of these pedons. The microscopic investigations were twofold in nature. The first stage involved the use of a petrographic microscope on thin sections of the Bt horizons for the purposes of descriptive micromorphology and modal analysis. The second stage was the use of the scanning electron microscope for the purpose of examining the arrangement of individual soil constituents on undisturbed ped surfaces on a three dimensional basis. The purpose of the microscopic approach was to characterize soil fabric of Bt horizons to gain further

understanding of properties of pedological features which could lend insight into processes operative in their formation on a comparative basis.

Surficial Geology

Site 1 The first site (to be referred to as Site 1) was located in Section 9 - Township 49 - Range 25 - West of the 5th Meridian. This area, southwest of Hinton, Alberta is located within the Foothills region of the province. The Rocky Mountain Foothills lie along the eastern margin of the Front Ranges of the Rocky Mountains as a narrow northwesterly tending belt (Roed, 1968). Roed describes the bedrock of the Foothills as being composed of a thick sequence of clastic rocks belonging mostly to the Brazeau Formation of Late Cretaceous age.

Soils developed on till of Cordilleran origin at this site have been mapped as the Robb Soil Association (J. Dumanski, personal communication). Parent material of the Robb Association is characterized by a medium texture, yellowish brown to olive brown color and generally showing a low lime content. The presence of relatively large amounts of well rounded meta quartzite cobbles causes Robb till to be classified as moderately to very stony. The most common landform associated with this till is ground moraine with relatively low local relief and a relatively shallow deposit resulting in covered but not masked underlying bedrock.

Site 2 The second site (to be referred to as Site 2) was located in the Northeast 1/4 of Section 5 - Township 52 - Range 13 - West of the 5th Meridian. This area lies in the Plains region of Alberta, 22 miles southwest of Nojack, marginal to the Foothills in

NTS map sheet 83G. The area is underlain by the Paskapoo Formation, of Early Tertiary (Paleocene) age (Twardy, unpublished soil survey report). The Paskapoo Formation is composed of sandstone and soft shales, primarily of fresh water origin.

The area was glaciated by the Continental Ice Sheet which advanced from the central region of Keewatin (Gravenor and Bayrock, 1955). Glacial till deposited in this area is primarily of Paskapoo Formation origin. The till from which the soils developed, in the area sampled, has been classified by Twardy (1969) as till of the Hubalta Soil Association. The till is characterized by an olive brown color, friable consistence, containing olive colored shale and coal fragments, and is generally stone poor. The texture of Hubalta till is clay loam, and the till has a low lime content. The predominant landform in the area studied is generally ground moraine showing an undulating to hilly topography at elevations between 2700 and 3500 feet M.S.L. The till deposits are relatively thick masking all underlying bedrock.

Site 3 The site chosen as the third area of study (to be referred to as Site 3) was located in the Northwest 1/4 of Section 3 - Township 61 - Range 13 - West of the 5th Meridian. This area lies in the Highland region of NTS map sheet 83J northwest of Whitecourt, Alberta and is adjacent to the Swan Hills to the northeast. The area is underlain by the Edmonton Formation (Wynnyk *et al.*, 1969) and to the north and south by the Paskapoo Formation. The Edmonton Formation of Late Cretaceous age is a brackish water deposit of bentonitic sandstone and

sandy shales.

The area was glaciated by the Continental Ice Sheet, as mentioned for Site 2. The till deposited at this site was classified by A. Twardy (personal communication) as "Hubalta" similar to that at Site 2. The predominant landform, a ground moraine, generally has an undulating topography with the till material being relatively thick masking all underlying bedrock.

Climate

Available climatic data[1] for extrapolation to Site 1 were very difficult to assess due to the fluctuations found in the Foothills region. The Foothills topography results in a climate which is locally dependent on aspect and altitude (Beke, 1969). The nearest location with well documented 28-year records was the meteorological station located at Entrance, 12 miles north-northwest of the site chosen.

Climatic data for Site 2 were obtained from the Edson meteorological station, 26 miles northwest of the study area. The data presented are based on 30 years of observations.

Climatic data for Site 3 were obtained from records based on 16 years of observations from the Whitecourt meteorological station, 18 miles southeast of the area sampled.

In general terms, the climate of the three areas, based on the data available, would be best described as cold subhumid. The growing season in all three areas is short with 51 frost free days at Entrance based on 28 years with a range of 101 to 3 frost free days

[1] All data taken from Climatic Norms, 1968, Canadian Meteorological Service, Vol. 1, 2, and 6. Toronto, Ontario.

recorded. Edson shows a slightly longer period with 63 frost free days from 30 years of observations with a range of 126 to 3 frost free days. Based on 16 years of recorded data Whitecourt shows a frost free period similar to Edson with an average of 63 frost free days and a range of 97 to 3 frost free days.

During the period from April to September all three sets of data show approximately the same mean daily temperature as shown in Figure 1. Winter months however show a general trend to coldest temperatures at Whitecourt and warmest at Entrance.

Annual precipitation is very similar in all three sets of data. Figure 2 shows that snowfall is greatest at Whitecourt and least at Entrance during the winter months. Precipitation (Figure 2) during the growing season is approximately equal in all three locations with a discontinuity appearing for Entrance during the month of July when Edson and Whitecourt receive approximately one inch more precipitation.

Vegetation

The three areas under study occur in the Boreal-Cordilleran Transition phytogeographic region of Alberta as characterized by Moss (1955) on the basis of the occurrence of lodgepole pine (*Pinus contorta*) and balsam fir (*Abies balsamea*) with white spruce (*Picea glauca*) as the dominant species in well drained areas.

Table 1 presents a percent cover estimate for vegetation on the three locations studied. The dominant species at Site 1 was lodgepole pine with an estimated cover of 40 percent with a very poor growth rate (J. Hermans, personal communication). In addition balsam fir, white spruce and black spruce (*Picea mariana*) occurred sporadically. Shrub vegetation

FIGURE 1. MEAN DAILY TEMPERATURE (°F) OVER A ONE YEAR PERIOD

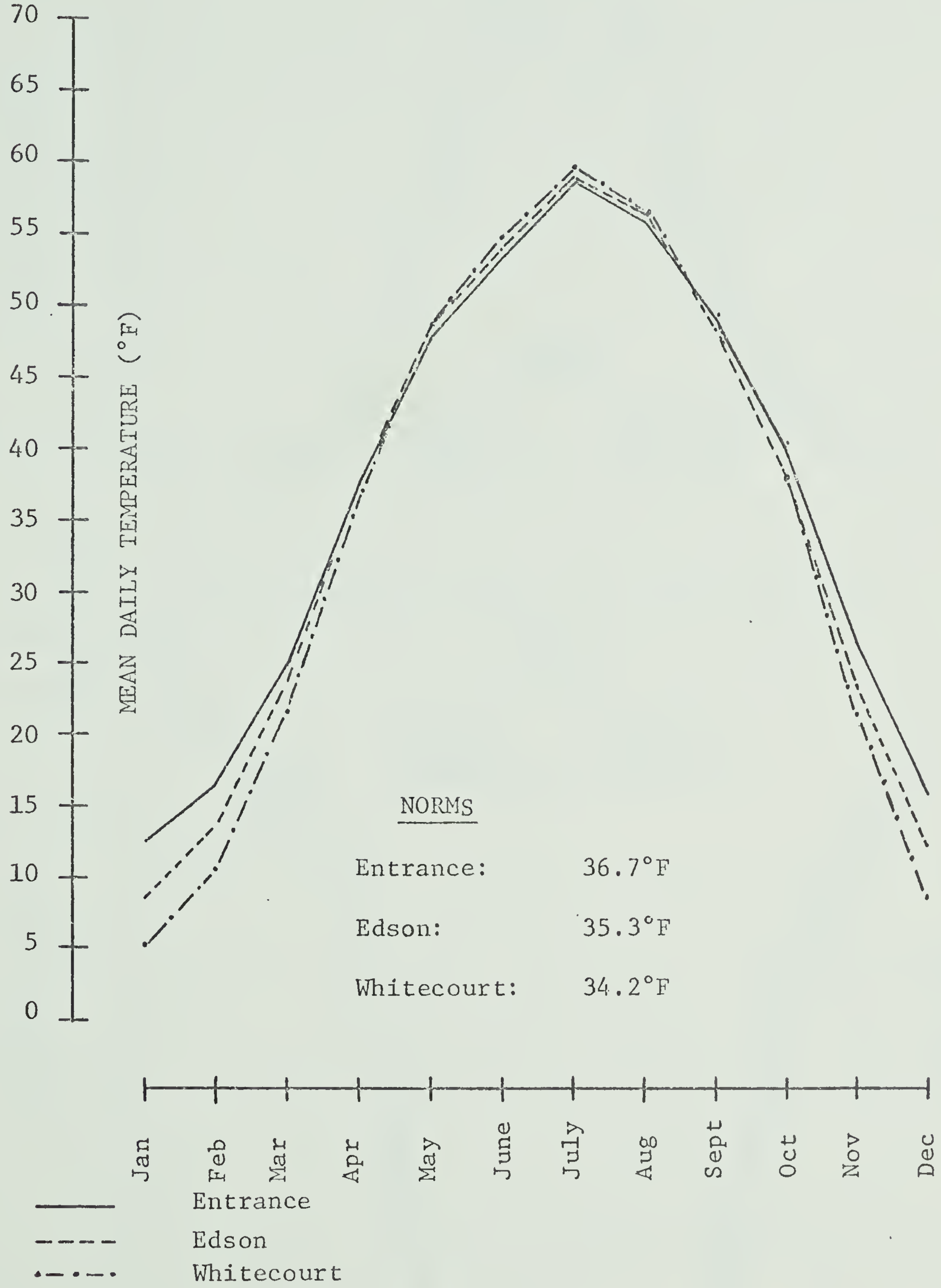
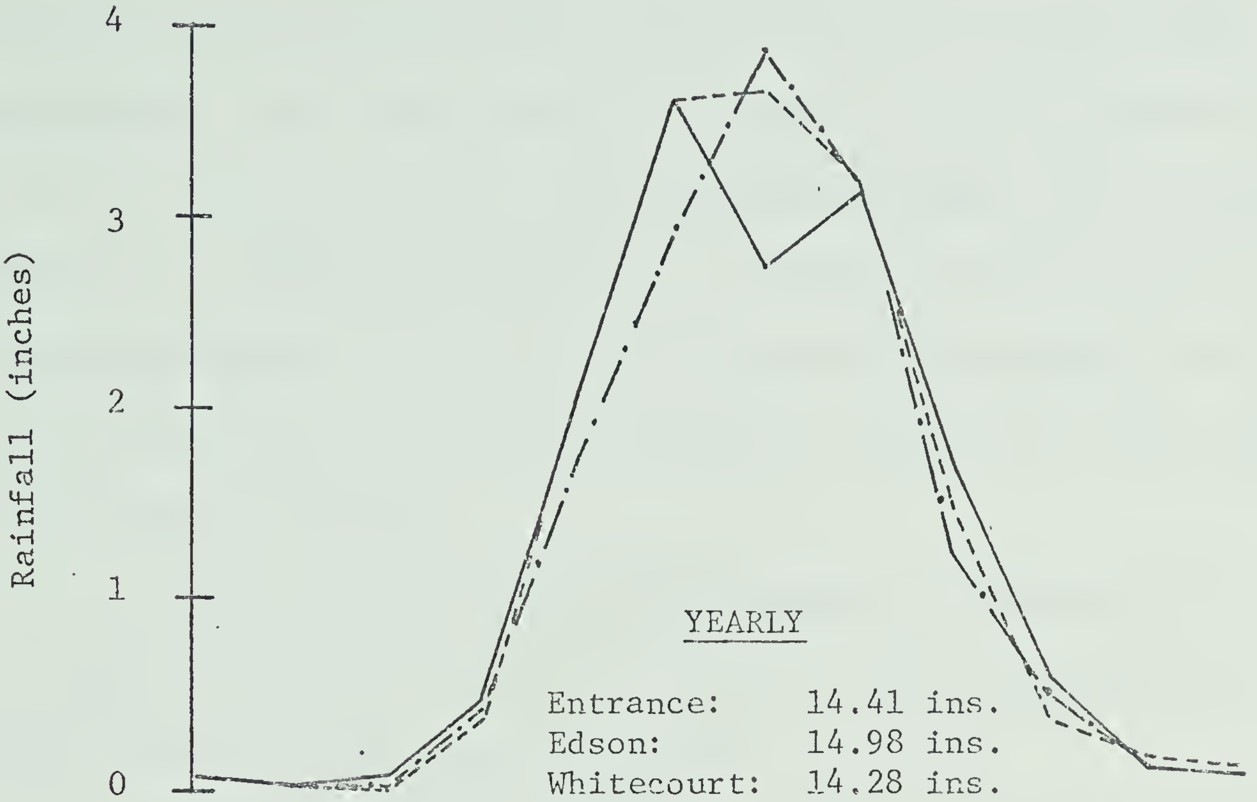


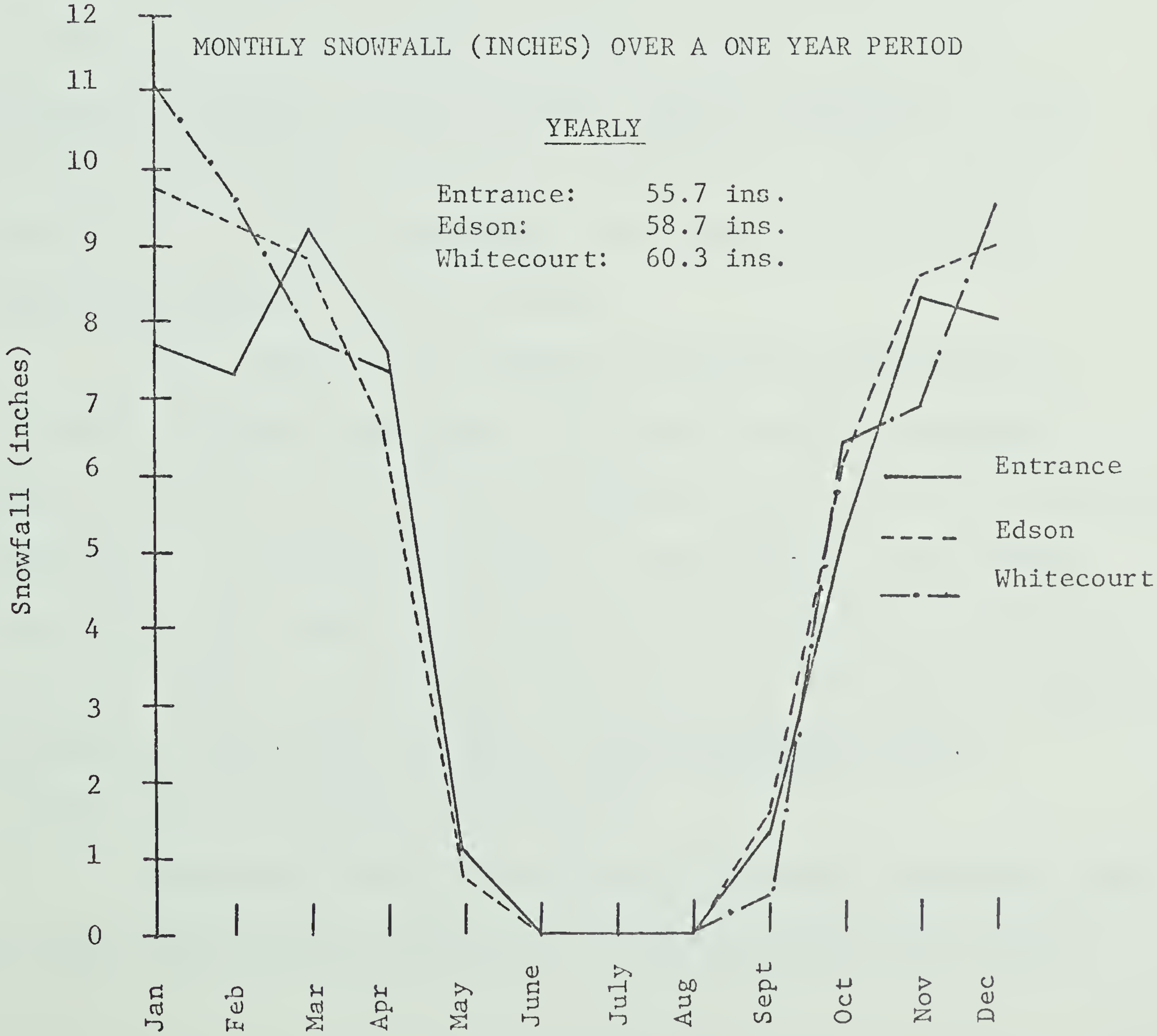
FIGURE 2. MONTHLY RAINFALL (INCHES) OVER A ONE YEAR PERIOD



YEARLY

Entrance:	14.41 ins.
Edson:	14.98 ins.
Whitecourt:	14.28 ins.

MONTHLY SNOWFALL (INCHES) OVER A ONE YEAR PERIOD



YEARLY

Entrance:	55.7 ins.
Edson:	58.7 ins.
Whitecourt:	60.3 ins.

at Site 1 was sparse with only a trace amount of wild rose (Rosa acicularis). Half shrubs were more prevalent with an estimated cover of 20 percent for bog cranberry (Vaccinium vitis-idaea) and 15 percent for Labrador tea (Ledum groenlandicum). In addition trace amounts of bunchberry (Cornus canadensis) and bog bilberry (Vaccinium uliginosum) were observed. Herbs and grasses, as indicated in Table 1, represented trace amounts of the vegetative cover.

Feather mosses (Hylocomium splendens and Ptilium spp.) represented an estimated cover of 50 percent taken in combination with lesser amounts of Lycopodium annotinum, a club moss.

Site 2 possessed the largest number of vegetative species as indicated in Table 1. The dominant species included aspen poplar (Populus tremuloides) and balsam poplar (Populus balsamifera) with an estimated percent cover of 25 and 10, respectively. Trace amounts of balsam fir, birch (Betula papyrifera), white spruce, and pin cherry (Prunus pensylvanica) were also present.

Shrub vegetation was abundant at this site with wild rose, honeysuckle (Lonicera involucrata) and low bush cranberry (Viburnum edule) the dominant species with an estimated cover of 10, 5 and 5 percent, respectively. As indicated in Table 1, trace amounts of other shrubs were present. The dominant half shrub was bunchberry with an estimated cover of 5 percent. In addition the presence of a large number of herbs dominated by common pink wintergreen (Pyrola asarifolia) with an estimated cover of 5 percent was observed.

The greatest difference observed in understory vegetation among the three sites was the presence of a 50 percent grass cover at Site 2

compared to only trace amounts at Sites 1 and 3. In addition trace amounts of ferns, mosses and lichens were present at Site 2.

The vegetative cover at Site 3 was most like Moss' (1955) description of characteristic vegetation of this phytogeographic region. The vegetation was dominated by white spruce with an estimated cover of 65 percent, balsam fir with an estimated cover of 5 percent and a trace amount of aspen poplar. Of the few shrubs and half shrubs present twin flower (Linnaea borealis) occurred in the greatest proportions yielding an estimated cover of 5 percent. As indicated in Table 1, the amount of herbaceous vegetation of Site 3 greatly exceeds that reported for Site 1 and is considerably less than that reported for Site 2. Trace amounts of grasses, ferns and lichens existed in this area but Hylocomium splendens and Lycopodium annotinum were abundant with an estimated cover of 60 percent each.

TABLE 1 SPECIES LIST AND OCULAR COVER ESTIMATES

Scientific Name	Common Name[1]	Estimated % Cover		
		Site 1	Site 2	Site 3
TREES:				
Abies balsamea	Balsam Fir	1	1	5
Betula papyrifera	Paper Birch	-	1	-
Picea glauca	White Spruce	1	1	65
Picea mariana	Black Spruce	1	-	-
Pinus contorta	Lodgepole Pine	40	-	-
Populus balsamifera	Balsam Poplar	-	10	-
Populus tremuloides	Aspen Poplar	-	25	1
Prunus pensylvanica	Pin Cherry	-	1	-
SHRUBS:				
Alnus crispa	Alder	-	1	-
Amelanchier alnifolia	Saskatoon	-	1	1
Lonicera dioica	Honeysuckle	-	1	-
Lonicera involucrata	Honeysuckle	-	5	-
Ribes hirtellum	Wild Gooseberry	-	1	1
Rosa acicularis	Wild Rose	1	10	1
Rubus pubescens	Dew Berry	-	1	1
Rubus pedatus	Raspberry	-	1	-
Salix spp.	Willow	-	1	-
Sorbus scopulina	Mountain Ash	-	-	1
Symphoricarpus albus	Snow Berry	-	1	-
Viburnum edule	Low Bush Cranberry	-	5	1

[1]According to Moss (1959)

TABLE 1 (continued)

Scientific Name	Common Name	Estimated % Cover		
		Site 1	Site 2	Site 3
HALFSHRUBS:				
Cornus canadensis	Bunchberry	1	5	1
Ledum groenlandicum	Labrador Tea	15	-	-
Linnaea borealis	Twin Flower	-	1	5
Lonicera dioica	Honeysuckle	-	-	1
Vaccinium vitis-idaea	Bog Cranberry	20	-	-
Vaccinium uliginosum	Bog Bilberry	1	-	-
HERBS:				
Actaea rubra	Bearberry	-	1	-
Aralia nudicaulis	Wild Sasparilla	-	1	1
Aster (showy) spp.	Aster	1	1	-
Castilleja spp.	Indian Paint Brush	1	1	-
Delphinium glaucum	Larkspur	-	1	-
Epilobium angustifolium	Fire Weed	1	1	-
Fragaria virginiana	Strawberry	1	1	1
Galium triflorum	Sweet Scented Bedstraw	-	1	1
Heracleum lanatum	Cow Parsnip	-	1	-
Lathyrus ochroleucus	Pea Vine	-	1	1
Maianthemum canadense	Wild Lily of the Valley	-	1	1
Mertensia paniculata	Tall Mertensia	-	1	1
Metilla nuda	Bishop's Cap	-	1	1
Osmorhiza longistylis	Sweet Cicely	-	1	1
Petasites palmatus	Colt's foot	1	1	1

TABLE 1 (continued)

Scientific Name	Common Name	Estimated % Cover		
		Site 1	Site 2	Site 3
Pyrola asarifolia	Common Pink Wintergreen	-	5	-
Pyrola secunda	One Sided Wintergreen	-	1	1
Smilacina racemosa	False Solomons Seal	-	1	1
Vicia americana	Vetch	-	1	-
Viola renifolia	Violet	1	1	1
GRASSES:				
		1	50	1
FERNS:				
Equisetum spp.	Horsetail	-	1	1
MOSSES:				
Hylocomium splendens	Feather moss	25	1	60
Lycopodium annotinum	Club moss	1	-	60
Ptilium spp.	Plume moss	25	1	-
LICHENS:				
Cladonia pyxdata	Reindeer moss	1	-	-

LITERATURE REVIEW

Soils of the Luvisolic Order (Canadian Soil Survey Committee, 1970) consist of well and imperfectly drained soils developed in moderate and cool climates under deciduous, mixed deciduous-coniferous or boreal forests, or under mixed forest-grassland transition zones. Parent materials from which these soils develop generally show a neutral to alkaline pH. The Gray Wooded (Gray Luvisol) Great Group of this order are soils with an organic surface horizon (L-H), a light colored eluvial horizon (Ae), and illuvial horizons in which clay is the main accumulation product (Bt).

Soils which would meet the criteria for the Canadian classification of Gray Luvisols have been reported by numerous researchers on a world-wide basis. Gray Luvisols develop on a variety of parent materials including till, alluvial, aeolian, outwash and lacustrine deposits. Processes of soil formation are controlled to a large extent by the physical and chemical properties of the parent materials. Ehrlich et al. (1955) reported on the basis of extensive analytical results that differences in parent material were the only variables in pedological processes among selected Gray Wooded, Brown Podzolic and Podzol soils developed in Manitoba. Extremes exist however. Beke (1969) suggested that parent materials have a lesser effect on pedogenesis than the topography, climate and vegetation in the Rocky Mountains in Alberta. Rode (1964) reviewed existing concepts of lessivage (translocation of materials without chemical breakdown) and podzolization (chemical decomposition, translocation and resynthesis) in 58 soils of

Russia and Eastern Europe. According to Rode's criteria both processes appeared to be operational in most of the soils with extremes existing in either process. The generally accepted process of development of Gray Luvisols in Alberta is similar to the European concept of lessivage (Pawluk, 1960). Processes involved do not entirely favor dissolution and resynthesis of clay minerals, but do favor a mild weathering process most active in the coarse clay fraction.

Till as a parent material for soil formation shows the greatest variability in composition. The variability may be attributed to differences in bedrock or modes of deposition on a regional basis (Buckman and Brady, 1968), as glacial till is found in a variety of irregular moraines such as terminal moraines, recessional moraines and ground moraines with associated kames, eskers and drumlins. Variation in composition over very short distances have been attributed to a complexity of factors related to ice mechanics and variability in bedrock erodibility (Pawluk, 1961).

Micromorphology

More detailed and complex descriptions of soil profiles both in the field and in the laboratory have come with the development of soil science. In its early stages soil science distinguished different kinds of profiles on the number and arrangement of recognizable horizons using two criteria, i.e. color and texture. These descriptions were amplified with the passage of time to include structure and consistence, presence of soluble salts and additional information from chemical, physical and mineralogical analyses (Brewer, 1960). Petrography as employed by sedimentary petrologists is a form of description of materials which

includes internal organization due to physical characteristics and arrangements of the constituents. Petrography is then also just another method of description but is based on a specialized outlook and requires specialized techniques. Use of microscopes and other instruments in this manner has enabled man to penetrate deeper, to see and know more (Kubiena, 1938).

The first principal of microscopic observations applied to soils is that the specimen must not be disturbed in its natural arrangement. Kubiena (1964) used an analogy of a watch crushed in a mortar and subjected to extensive analytical testing and posed the question as to whether one would ever visualize the component parts, and if so their arrangement and function in the original structure. The main value then of microscopic description using petrographic methods is a more comprehensive description allowing detailed study of characteristics of soil materials neglected by other descriptive means. Kubiena (1964) carried the value of petrography as related to soils one step further. He stressed that the microscopic aspect is necessitated since the majority of individual constituents of a soil only become visible under magnification and that pedological events occur in microscopic dimensions.

Examination of soils in thin section reveals a great deal of detail otherwise unavailable. It is very important for the micropedologist to select the essential features from an abundance of material and to present it with particular emphasis (Kubiena, 1964). The essence in brief is substance and form, for the whole depends on a combination of both. Brewer (1960) defined these in terms of "soil structure" and "soil fabric":

> "Soil structure is the physical combination of a soil material expressed by the size, shape and arrangement of the solid particles and voids, including in the former both primary particles to form compound particles and the compound particles. Soil fabric is the element of structure which deals with arrangement."

Kubiena (1938) pointed out that the constituents of soil can be divided into two broad groups on the basis of their physical and physiochemical properties: "fabric skeleton" and "fabric plasma" with reference to the relatively stable and mobile constituents, respectively. With the definitions of fabric and plasma as defined by Brewer (1960), the adjective fabric appeared incongruous and led Brewer and Sleeman (1960) to redefine the terms concisely, retaining Kubiena's original concepts:

> "1. Skeleton grains of a soil material are individual grains which are relatively stable and not readily translocated, concentrated, or reorganized; it includes mineral grains and resistant siliceous and organic bodies larger than colloidal size. Complex grains are not considered as skeleton grains but as pedological features. The skeleton, as such is relatively immobile except for processes such as washing down cracks, but is capable of weathering to form plasma."

> "2. Plasma of a soil material is that part which is capable of being, or has been moved, reorganized, and/or concentrated by the processes of soil formation. It is the mobile active part of the soil material. The plasma includes all of the material, mineral or organic, of colloidal size and relatively soluble material which is not bound up in the skeleton."

The reorganization of soil constituents due to the nature of the constituents and to the multitude of soil forming processes leads to the formation of features which have recognizable structures and fabrics. Brewer and Sleeman (1960) referred to these as pedological

features, defined as:

> "recognizable units within a soil material which are distinguishable from the enclosing material for any reason such as origin, differences in concentration of some fraction of the plasma, or differences in arrangement of the constituents".

Considering current terminology and concepts in pedology and petrology Brewer and Sleeman (1960) proposed a descriptive system of pedological features. The search for suitable existing concepts emphasized the considerable confusion existing in published works in petrology and pedology in terms of overlapping definitions and the same term being used for differing concepts. An attempt was made by Brewer (1964a) to develop a system specifically for soils allied as closely as possible to concepts in petrology. Terms were proposed for many quite specific pedological features using single, simple, precisely defined terms which would allow recording of these features, described in considerable detail. Such pedological features include cutans, pedotubules, glaebules, crystallaria, subcutanic features, and fecal pellets all due to translocation of plasmic materials, biological activity or the rearrangement of soil materials _in situ_.

Since the plasma is the mobile portion of the soil materials it can exhibit a wide variety of arrangements caused by behavior of soil materials under different conditions. Brewer (1964b) working from the premise that s-matrices are not entities with definite boundaries, but the background material within which pedological features occur presented a classification of plasmic fabrics. The plasmic fabric is the organization of the constituents of the plasma and associated very small voids, which result from the packing of

plasma grains within the s-matrix of the soil material or of individual pedological features. The description and classification of plasmic fabrics is based on interpretation of optical properties under crossed nicols, especially extinction phenomena due to visible crystals of plasma, the kind and degree of orientation of plasma grains, the kind and degree of preferred orientation of domains which cause striated orientation patterns, and the kind and degree of plasma separations.

Micromorphological studies have assisted in various forms of soil research by revealing significant properties which had previously received little attention. It has provided a basis for investigation of phenomena which occur in the processes of soil formation, soil physics, and soil-plant relationships.

Fabric of Bt Horizons

Kubiena (1938) described the fabric of compacted soil horizons which are divided into numerous portions displaying characteristic sizes and shapes as "cleavage blocks". He characterized these cleavage blocks by a crust formation similar to that which previously had been observed on surfaces of aggregates. Present terminology would define these cleavage blocks as peds (Soil Science Society of America, 1970) and the surface crusts as cutans (Brewer, 1964a). In soils possessing cleavage blocks Kubiena reported the occurrence of "channel fabric" (leitbahngefüge). Channel fabric was recognized if the ground mass of the soil body showing skeleton and plasma in a definite arrangement is traversed by numerous tubes and veins containing plasma substances.

Since this initial work much micromorphological research has

substantiated the original observations on Bt horizons and elaborated on them considerably. Micromorphological research has demonstrated that in general argillans are characteristically present in Bt horizons. Argillans as defined by Brewer (1964a) are that broad group of cutanic features composed dominantly of clay minerals. Commonly the clay minerals are mixed with some contaminant in the form of sesquioxides or hydroxides. The occurrence of argillans in Bt horizons is in the form of coatings on voids, peds and skeleton grains.

Mineralogically argillans are usually similar to the clay of the s-matrix with various constituents concentrated in them. This has been shown by Buol and Hole (1959), and Grossman et al. (1964) by removal of surficial argillans from peds and comparative X-ray analysis with the clays of the s-matrix. Recent work by Beke and Zwarich (1971) on Gray Luvisols in Manitoba suggests a lesser proportion of smectite and more mixed-layer clays in the coarse clay fraction of cutans than of the matrix. The fine clay fraction of the cutans contained more smectite and vermiculite but less mixed-layer clays than the matrix.

Usually the clay mineral grains in argillans are oriented with their (001) plane parallel to the surface on which they occur. This was noted by McCaleb (1954) who observed that clay particles and associated iron oxides are oriented with their C-axis perpendicular to the pore wall in vertical thin section and appeared as concentric rings in horizontal thin section. More recent work by numerous researchers has reported this orientation as a diagnostic feature (Stephen, 1960). Occasionally optically oriented clays occur as plasma separations in Bt horizons displaying sepic plasmic fabric (Brewer and Sleeman, 1969). These are recognizable as elongated zones with striated orientation usually

interspersed with plasma, occasionally traversing the body of the s-matrix. Usually however, this form of clay orientation is associated with voids and skeleton grains.

Argillans occurring on void walls and ped surfaces are usually attributed to the pedological process of illuviation of the fine clay fraction (Harpstead and Rust, 1964) or formation in situ (Brewer, 1968). McCaleb (1954) suggested from observations of optical orientation that forces of surface tension operating on colloidal suspensions or solutions resulting in clay synthesis were the causitive elements in the formation of argillans. Brewer (1956) reported that dense B horizons in which there are relatively few, but large channels, quite commonly have coatings of strongly oriented clay on the walls of large channels supporting the suggestion that oriented clays have moved as colloidal suspensions because relatively large channels are necessary for movement and concentration of clays. Grossman et al. (1964) proposed that oriented clays on void peripheries may form in some instances from deposition of illuvial clay. Another means of formation suggested was clay orientation induced by shear along planar surfaces during wetting and drying of the soil. This possibility also was suggested by Day and Holmgren (1952) based on stresses on small contact points between aggregates caused by overburden. In addition Grossman et al. (1964) suggested that roots may also cause preferred orientation by shear.

Such inferences as those mentioned above concerning pedological processes have led in many instances to laboratory experimentation intended to reproduce phenomena observable in soil materials. Thorp et al. (1957) used columns of soil material from Bt horizons of Miami soils, through which were intermittently passed various salt solutions. In addition to the mobilization of ions the resulting suspensions revealed

detectable amounts of fine silicate clays moving in suspension. Redeposition of iron compounds was observed associated with developed colloidal films, holding originally discrete soil particles together. Brewer and Haldane (1957), working with artifically induced clay orientation in sand columns reported that the type of accumulation and degree of orientation developed by the movement of clays in suspension depend on:

(a) the proportion of clay to sand. (Observations indicated no orientation for sand-clay mixtures in which the proportion of clay is more than sufficient to completely fill the pore spaces between sand grains. When the proportion of clay is less than this, the clay material formed bands about the sand grains on drying.)

(b) the freedom of movement of the individual clay particles. (The addition of silt reduces available pore space causing less freedom of movement.)

(c) The force exerted by the conducting film of water or clay suspension as the mixture is dried.

(d) the shape of the clay size particles.

Similar results were obtained by Buol and Hole (1961) in passing clay suspensions through sieved loess. These proposed causal factors were partially supported by Bartelli and Odell (1960) where the study of eight pedons showed that an increase in clay content in the C horizon resulted in a decrease in oriented clay deposits in the B horizon.

Cutanic features in Bt horizons occurring on skeleton grains may be grouped into two categories: (1) free grain cutans and (2) embedded grain cutans (Brewer, 1964a). In the case of the free grain cutans the

features occur on the surfaces of grains forming the walls of voids. This form of argillan is generally attributed to illuviation as discussed above (Brewer and Haldane, 1957; Bartelli and Odell, 1960; and Brewer and Sleeman, 1969). Cutanic features occurring on surfaces of skeleton grains embedded in the s-matrix may be inherited from the parent material (Brewer and Sleeman, 1969) or may form a "quasiargillan" caused by pedoturbation as proposed by Hole (1961). Pedoturbation may take the form of soil mixing by the action of freezing and thawing, expansion and contraction of montmorillonite clay-rich soils as suggested by Brewer (1964a), noncatastrophic mass wasting, movement of gas, or by mixing with water in the soil profile. Gile and Grossman (1968) attribute the lack of cutanic features on ped surfaces and the abundance of clay coatings on sand grains within peds to a lesser amount of abrasion on the inped sand grains than on the ped surfaces during moisture fluctuation and associated expansion and contraction.

Plasma separations (clay streaking), observed in patches or elongated zones with striated orientation, are characteristic of sepic fabrics (Brewer and Sleeman, 1969; Grossman _et al._ 1964). Usually the striations are interspersed with plasmic materials and may be associated with voids, skeleton grains or may traverse the body of the s-matrix. Buol and Hole (1961) attributed oriented clay deposits on the interior of peds to previous formations on walls of large voids. Due to processes of pedoturbation (Hole, 1961) they were incorporated into the ped interior. The study of argillic horizons of desert soils by Gile and Grossman (1968) revealed oriented clays within peds which they considered as remnants of oriented clays formed on ped surfaces during

Pleistocene pluvial periods. Brewer (1964a) and Brewer and Sleeman (1969) proposed the dominant causal factor in the formation of these plasma separations to be differential movement due to irregular wetting and drying causing plastic flow without actual cracking to form recognizable planar voids. Controlling factors were: proportion and species of clay minerals, kinds of exchangeable cations, severity of the regime of wetting and drying and the presence of solid particles.

Although argillans are generally associated with B horizons of maximum clay percentage, being a small proportion of the total clay, no distinct correlation exists between total clay content and areal proportion of argillans. Similarly no correlation exists for the proportion of argillans in relation to the depth in the pedon. Argillans may occur in any horizon including the Ae (Brewer, 1968) and may have maximum development at any depth in the Bt horizon as reported by McCaleb (1959), Thorp *et al*. (1965), or in the C horizon (Hendricks *et al*. 1962; Buol and Hole, 1961).

MATERIALS AND METHODS

Sampling

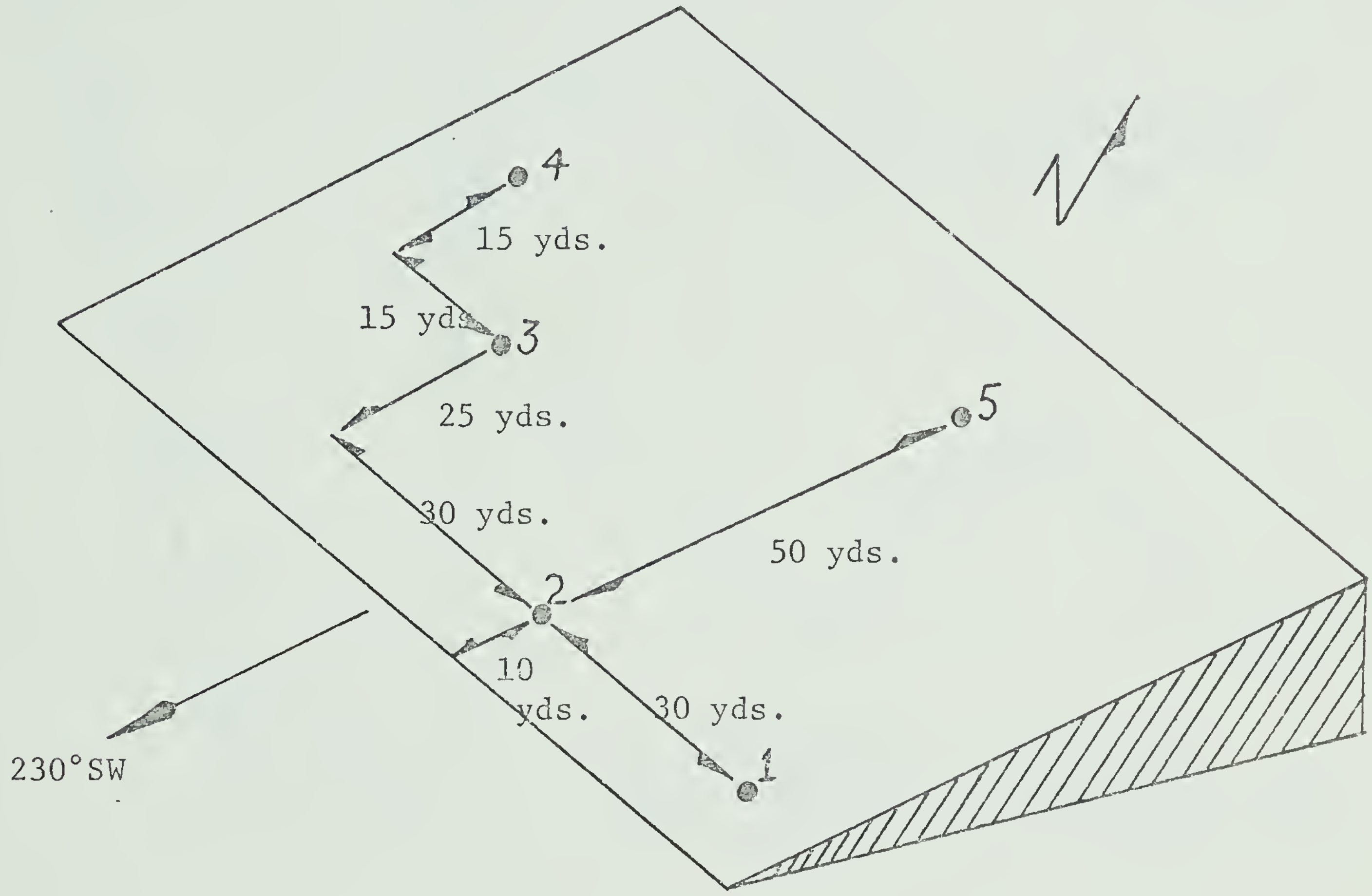
Five pedons representative of the soil series mapped in the area were selected at each of the three sites as described in Figures 3, 4 and 5. Each pedon was described morphologically and a bulk sample obtained according to horizon sequence for purposes of physical, chemical and mineralogical analyses. Each site was described with respect to vegetation, slope, aspect and elevation. Bt horizons in each pedon were sampled for micromorphological investigation by removal of large undisturbed clod samples which were placed in pressed paper cylindrical containers and padded with "Kleenex" tissues to reduce sample disruption during transport. Each individual Bt horizon was sampled both in the upper and lower portions. The time of sampling was the second week in June, the third week in June, and the third week in July, 1969 for Sites 1, 2 and 3, respectively.

Bulk samples were air dried and the soil peds crushed in a steel roller mill to pass a 2 mm sieve and stored in glass screw-top containers. Samples taken for micromorphological investigations were air dried within the pressed paper cylinders prior to impregnation of selected portions.

Additional samples were taken in triplicate using a 5 cm, inside diameter, core for purposes of bulk density measurements. Upon removal these cores were placed in plastic sealed containers to prevent loss of moisture.

FIGURE 3.

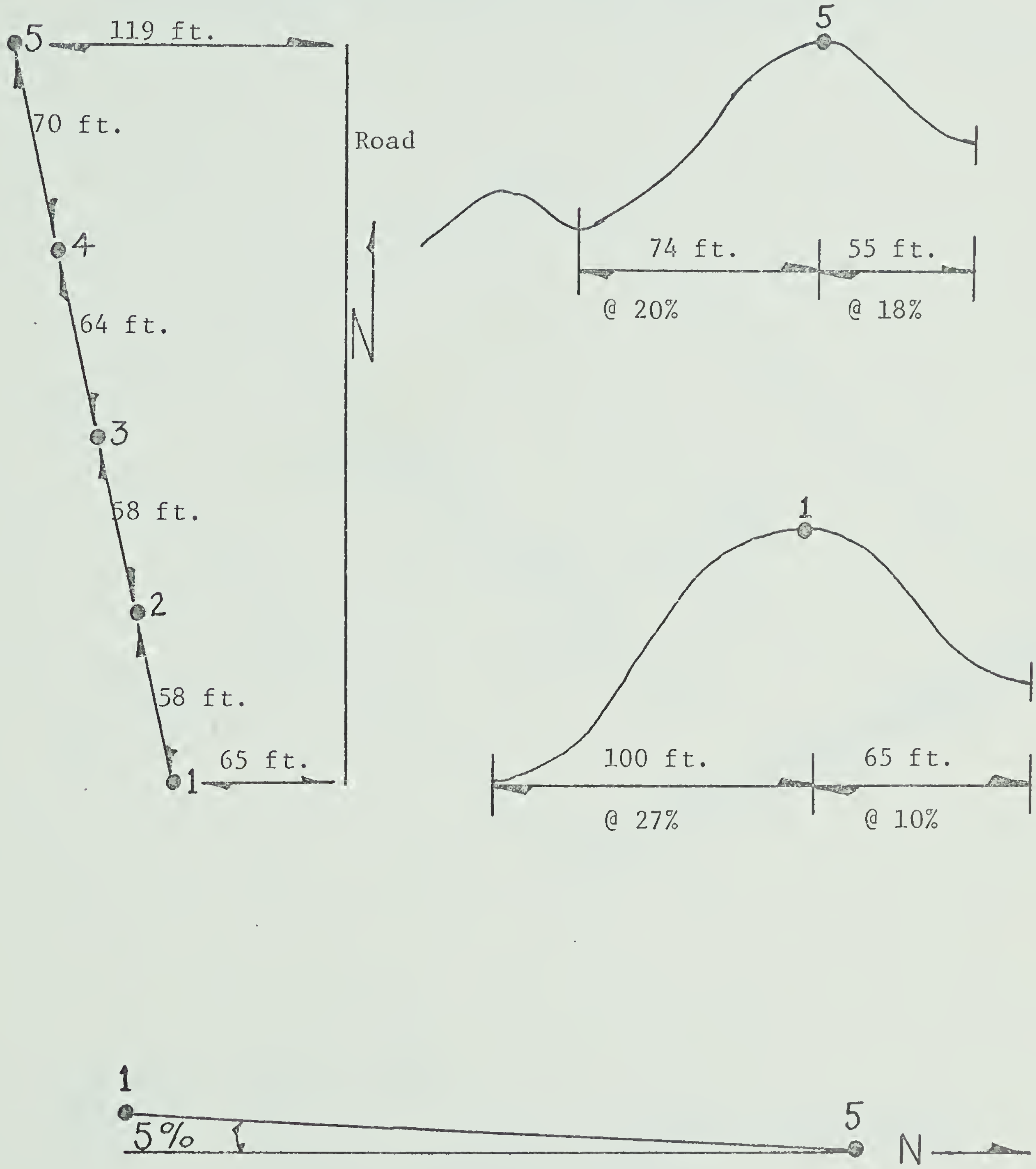
LOCATION OF PEDONS SAMPLED AT SITE 1 (S9-TP49-R25-W5)



Elevation: 4500 ft MSL (est.)
Slope: 18%
Drainage: Well drained

FIGURE 4.

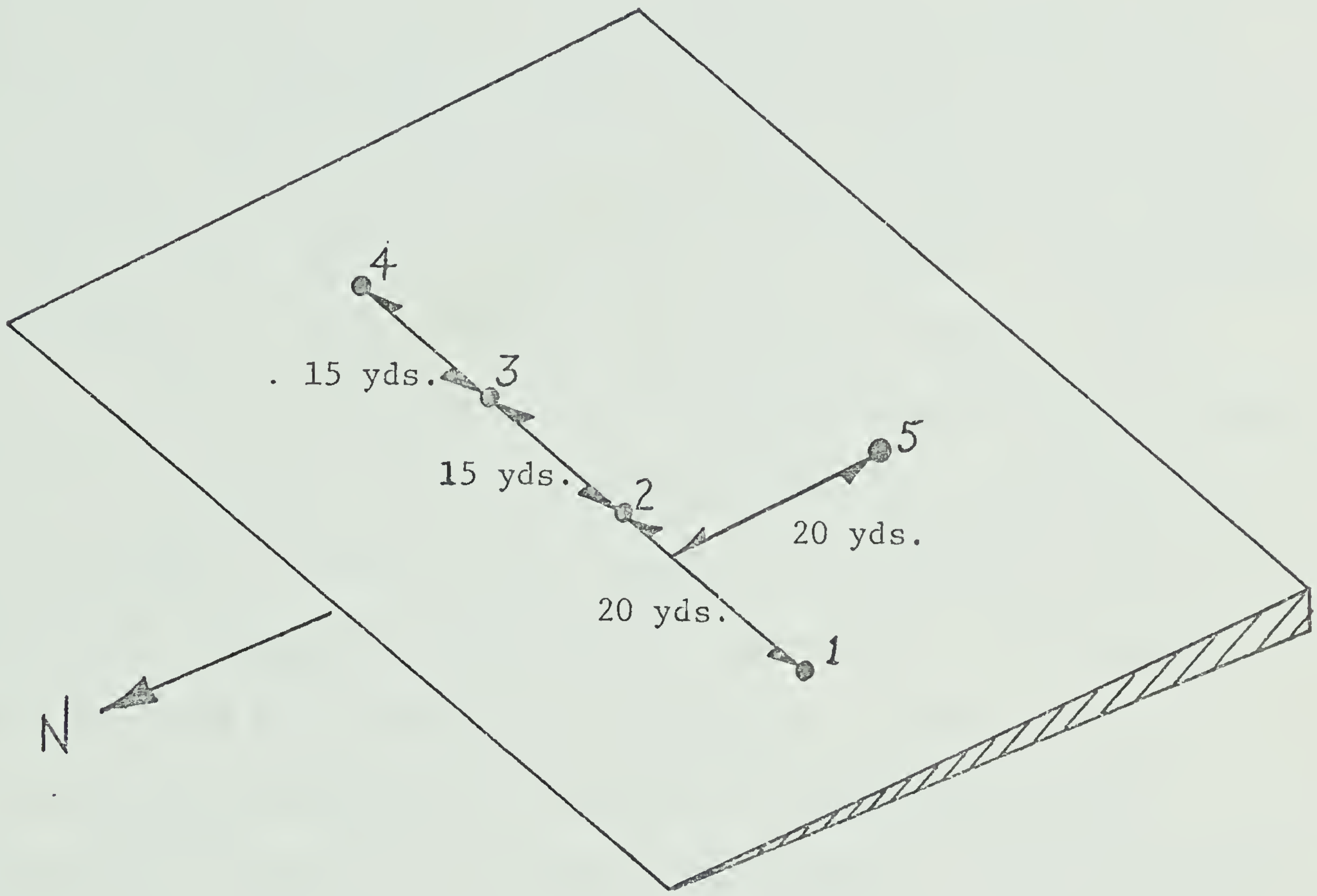
LOCATION OF PEDONS SAMPLED AT SITE 2 (NE5-TP52-R13-W5)



Elevation: 3350 ft. MSL
Slope: As Diagramed
Drainage: Well Drained

FIGURE 5.

LOCATION OF PEDONS SAMPLED AT SITE 3 (NW3-TP61-R13-W5)



Elevation: 2925 ft. MSL
Slope: 3%
Drainage: Pedons 1, 2, 3 and 4 - Moderately well drained
Pedon 5 - Imperfectly drained

Physical Analyses

(a) Bulk Density. Bulk density measurements were made according to the procedure described by Bradfield and modified by Lutz (1947) using a core with an inside diameter of 5 cm to obtain triplicate samples. In the case of Site 1, bulk densities in Bt horizons were measured by the "rubber balloon method" using a Soiltest Volumeasure as described by Blake (1965) due to the presence of large rock fragments which prevented the removal of undisturbed core samples. Values reported as bulk density are those obtained from untreated samples. Values reported as corrected bulk density are representative of the fine earth fraction of the sample. After the bulk density samples were oven-dried and weighed, the material was slaked in a solution of a dispersing agent (Calgon) and passed through a 2 mm sieve. The coarse fragment fraction thus separated was oven-dried, weighed, and the volume measured by displacement of water in a graduated cylinder. Corrected bulk density was calculated using weight and volume measures obtained after subtraction of the respective coarse fragment values.

(b) Moisture Content. The natural moisture was determined by oven drying core samples at 105°C for a period of greater than twelve hours. The value reported is the mean value, based on oven-dry weight of samples taken in triplicate.

(c) Particle Size Analysis. Particle size analysis was done by the method outlined by Toogood and Peters (1953) modified by the addition of 0.2N HCl to remove carbonates. The fine clay content was determined by evaporation of an aliquot separated from the total

clay fraction by centrifugation as outlined by Baver (1959). Mechanical analyses were done in triplicate for all samples from Site 1 and in duplicate and triplicate for selected samples from Sites 2 and 3. Mean values are reported.

Chemical Analyses

(a) Soil Reaction. pH was determined in a 0.01 M calcium chloride soil suspension (1 part soil: 2 parts solution by weight) as recommended by Peech *et al.* (1953) using a Beckman Zeromatic pH meter and glass and calomel electrodes.

(b) Total Carbon. Total carbon was determined by dry combustion using a Leco induction furnace as outlined by Allison *et al.*, (1965). Inorganic carbon in the BC horizons of pedons at Site 1 and C horizons at Sites 2 and 3 was shown to be negligible. Total carbon values may be interpreted as organic carbon.

(c) Total Nitrogen. Total nitrogen was determined for each horizon using the Kjeldahl method of Jackson (1958). Reagents used were mercurous oxide, copper sulfate and potassium sulfate as a catalyst.

(d) Exchange Acidity. Exchange acidity was determined by leaching the soil with 0.5N barium acetate adjusted to pH 7.0 and titrating the leachate with standardized NaOH as suggested by Brown (1943).

(e) Exchangeable Cations. The exchangeable cations (Ca^{2+}, Mg^{2+}, Na^{+} and K^{+}) were extracted from the samples with 1N ammonium acetate adjusted to pH 7.0 as outlined in Association of Official Agricultural Chemists (1955). The exchangeable cations were determined

with a Perkin Elmer Model 303 Atomic Absorption Spectrometer.

The results from all analyses were corrected from air dry weights to oven dry weights before being reported.

X-Ray Diffraction

Clay separations and oriented glass slide mounts of Mg- and K - saturated clays (Kittrick and Hope, 1963) were prepared for the less than 2μ clay fraction. X-ray diffraction patterns were obtained with a Philips X-ray diffractometer using nickel filtered Cu $K\alpha$ radiation at a scanning rate of 2 degrees 2θ per minute. Clays used for X-ray diffraction patterns were subjected to the following treatments:

(a) Magnesium saturated, air dry (Mg-air dry)

(b) Magnesium saturated, glycolated (Mg-glycol)

(Slides were prepared by placing magnesium saturated, air dry, oriented slides in an ethylene glycol saturated atmosphere at 60°C for 48 hours.)

(c) Potassium saturated, air dried and heated to 105°C for 24 hours. (K-105°C)

(d) Potassium saturated, air dried and heated to 550°C for 4 hours. (K-550°C)

Micromorphological Analyses

The oriented vertical portions selected in duplicate from the larger clod samples were impregnated under vacuum using the technique of Innes and Pluth (1970) developed for preparation of thin sections of materials with high clay contents and high bulk density. A thin section was

prepared from each of the Scotchcast No. 3 impregnated samples by a procedure recommended by J. Dumanski (personal communication). The fabric of each thin section was then systematically described following the scheme outlined by Parfenova and Yarilova (1962) employing terminology devised by Brewer (1964a) at a magnification of 32x.

Modal Analysis

Micromorphology is simply a detailed method of description. As outlined by Parfenova and Yarilova (1962) such descriptions lead to a further understanding of the complex composition and array of soil materials. Modal analysis as used by petrographers yields additional information through identification of constituents and estimation of areal and/or volumetric proportions (Chayes, 1956). By modal analysis in petrography one determines mineralogical composition. Likewise the modal analysis of soils is understood to be the determination of the mineralogical composition of soils (Anderson and Binnie, 1961). The difference in modal analysis between pedography and petrography is that with unconsolidated materials, such as soils, pore space and organic constituents, in addition to mineral constituents are needed to specify the mode completely.

Griffiths, as cited by Dumanski (1970), states that absolute identification of a constituent is an impractical ideal in the majority of cases. Definition of mutually exclusive and readily identifiable categories offers the least possible compromise between "absolute measurements" and relatively precise estimates. Classification of the material is then accomplished by counting the frequency of each class

following a standardized procedure. A total of 400 points were counted on one of each set of duplicate thin sections from randomly selected traverses of 50 or 100 points each (dependent upon thin section dimensions). Percentage distributions by horizons within each pedon and mean values for the 5 pedons at each site were calculated. The latter information was plotted against pedon morphology and depth to yield a volumetric estimation of distribution of materials through the Bt horizons.

For modal analysis the constituents of the thin sections were classified into thirteen categories according to the following criteria.

Skeletal Material (grains greater than 10μ diameter)

1. Minerals - quartz, feldspars, microcline, hornblende and other crystalline grains showing uniform, parallel or cross-linked extinction patterns.

2. Rock Fragments - any consolidated constituent with a discernible boundary and composed of two or more minerals, such as sandstone, siltstone or shale. This category also included chert fragments, coal fragments and metallic concretions.

Voids

3. Orthovughs - pores, without a coated interior, caused by mode of packing, or any mechanism of pedoturbation occurring within the s-matrix of a ped.

4. Metavughs - pores with a coated interior caused by the mode of packing, or any mechanism of pedoturbation occurring within the s-matrix of a ped.

5. Planes - voids considered planar according to the ratio of their principal axes, which by their shape and extent constitute a deviation from normal packing of plasma and skeleton grains. Planes are usually separations of peds but may be intrapedal and may or may not have smoothed walls.

6. Other voids - includes all pore spaces observable at the magnification used which are unclassifiable into any of the other groups. This may include vesicles or voids around skeleton grains caused by drying.

Plasmic Materials (material less than 10μ in diameter with the exception of organic matter.)

7. Plasma around skeletal material - plasmic substances which do not exhibit orientation patterns directly adjacent to a skeleton grain by a distance not greater than 35μ.

8. Random plasma - plasmic materials within the s-matrix which exhibit no preferred orientation pattern and are not adjacent to any void, skeleton grain or fragment of organic matter.

9. Other plasma - plasmic materials which do not exhibit preferred orientation that is unclassifiable in the other groups. This may include non-oriented plasma adjacent to voids or organic matter.

Cutans

10. Plane cutans - plasma accretions associated with the walls of planar voids including both intra- and interpedal planes.

11. Vugh cutans - plasma accretions associated with the walls of voids occurring within peds.

12. Other cutans - plasma accretions unclassifiable into

other groups. This may include plasma separations formed *in situ* by modification of the s-matrix by pedoturbation and oriented plasmic constituents surrounding skeleton grains.

13. Organic Matter - tissue fragments at various degrees of decomposition identifiable by cellular units or organic staining on surrounding plasma.

Scanning Electron Microscopy

The principle upon which the scanning electron microscope operates, is the bombardment of a specimen surface with a thin beam of electrons, 100 Å in diameter or less. The diameter of the beam and the beam location relative to the sample surface are controlled by electromagnetic lenses. The focused beam is moved over the surface of the specimen by means of electromagnetic coils. When the beam of electrons strike an area on the sample surface a portion of the electrons are absorbed into the sample resulting in an energy release and the emission of secondary electrons of lesser energy. In addition some of the electrons from the electron beam are reflected from the surface. Electrons leaving the surface of the specimen due to the actions of the electron probe are attracted toward an electron collection system. This consists of an electrostatic focussing electrode and a scintillator optically coupled to a photomultiplier. Electrons impinging upon the scintillator release photons which travel to a photomultiplier. Signals are then passed through a series of amplifiers to a video display unit, where the amplified signals modulate the brightness of the cathode ray tube beam. This impulse in turn produces a spot on the cathode ray

tube. The beam scans the tube face of the display unit in synchronism with the scanning of the specimen by the electron beam. In practice two cathode ray tubes are employed; one for the purpose of video display for direct observation and the other for image photography.

The instrument used for this portion of the research was a Stereoscan Scanning Electron Microscope, Type 96113, Mack 2A, produced by Cambridge Instrument Company Limited. The specimen stage can accommodate specimens up to 12 mm in diameter and 3 mm in thickness without affecting rotational adjustments allowing observation of all exposed surfaces. Specimens with dimensions less than or equal to the above may be moved in a plane normal to the beam optical axis in two directions, 90° relative to one another, over distances of 16 mm in the X direction and 13 mm in the Y direction. In addition the specimen may be moved parallel to the axis of the beam (the Z axis) a total of 10 mm. The stage can be rotated through any angle up to 90° about an axis perpendicular to the beam, and rotated through 360° about the axis of the mounting stub.

In order that sample surfaces could be examined in the abovementioned manner, selected individual peds were taken from air-dried clod samples. In many instances the ped size necessitated fracture in such a way as to retain orientation of the specimen in relation to the soil profile. Individual specimens were placed in aluminum foil dishes, 10 mm in diameter and 3 mm in depth containing Lakeside 70, used to cement the specimen in a desired orientation as recommended by J.E. Gillott (personal communication). In addition mounting of the specimens in this manner allowed greater areal contact to the mounting stub, reducing

the effect of sample charging. The aluminum foil dish was in turn attached to the mounting stub using an epoxy resin.

If a specimen is electrically insulated, as were these mounted soil specimens, it is necessary to coat it with a conducting layer, usually a thin layer of metal. This coating reduces the possibility of surface charging under the electron beam. This coating is generally not required when the scanning electron microscope is used at low voltages (below 3kV), however the performance of the instrument improves at higher accelerating voltages making it preferable to coat the specimen and use a voltage of 20kV.

The metal used to coat the specimen was a gold-palladium alloy applied in a "Speedivac" Coating Unit, Model 6E4, produced by Edwards High Vacuum, Crawley, Sussex, England. The operating parameters of this unit included a pressure of less than 10^{-4}mm of Hg and constant rotation of individual samples as well as constant rotation of the mounting stage during atomization of the alloy. Rotation of this nature is necessary on samples with irregular surfaces in order to insure adequate coverage. The gold-palladium alloy was atomized using a tungsten filament under a potential of 6 volts and a current of 100 amps.

Individual samples from the three sites prepared in the above manner were examined with the scanning electron microscope under an applied voltage of 20kV. An attempt was made to view constituents and features of fabric which had been observed in thin section from other replicate samples. Photographs were taken at various magnifications and from various angles of these features for more detailed descriptions of the arrangement of components.

RESULTS AND DISCUSSION

For purposes of discussion the results obtained are presented in three parts. The first part deals with results obtained in field and laboratory studies conducted for the purpose of characterization of soils at each of the three sampling sites. The second part refers to fabric analyses done on thin sections prepared from selected peds of Bt horizons. Micromorphological data are presented in terms of description and in terms of results obtained from modal analysis. The third portion concerns experiments conducted with the scanning electron microscope on selected samples of Bt horizons, as another means of soil fabric examination.

I. CHARACTERIZATION

A. Macromorphology

Morphological descriptions of each individual pedon at each of the three sites studied are presented in the Appendix in conjunction with results obtained for physical and chemical analyses conducted on samples from the individual pedons. This information was used to prepare the following morphological characterization of the soils, discussing variability in properties existing at each site and a comparison of observed features among sites.

Site 1. The Coalspur Series investigated at Site 1 had characteristic profile horizonation of L-H, Ae or (Ae_1, Ae_2), Bt and BC. The C horizon was impossible to differentiate in terms of macromorphology due to lack of carbonates and no observable color, structural, or textural differentiation from the BC. Bedrock occurred at estimated depths of three to four feet in the pedons.

The surface organic (L-H) horizon in all five pedons was composed dominantly of the remains of mosses with appreciable amounts of labrador tea and bearberry. Some grass and herb remains were observed to a limited extent. The relatively thin (2 to 3 inches) Ae_1 horizon, of silt loam texture, in pedons 1, 2 and 3 was grayish brown to brown (10YR 5/2 to 10YR 5/3) in color under natural moisture conditions and when dry exhibited a pale brown (10YR 6/3) color. The structure of the Ae_1 horizon varied from massive to weak fine subangular blocky, to moderate medium subangular blocky, of very friable consistence, which broke to a weak fine platy or weak medium platy structure. The Ae_1 horizon had a clear smooth boundary in the three pedons.

The Ae_2 horizon of pedons 1, 2 and 3 was a brown to yellowish brown (10YR 5/3 to 10YR 5/4) colored silt loam under natural moisture conditions and dried to a very pale brown to light yellowish brown (10YR 7/3 to 10YR 6/4) color. The structure observed in the Ae_2 horizon was variable from a moderately developed medium to fine platy, to a strong fine to medium platy of very friable consistence, which broke to a fine granular or crumb structure. The horizon boundary was in all cases diffuse.

Pedons 4 and 5, located further up slope, had a comparatively thick (8 and 12 inches) Ae horizon with characteristics very similar to Ae_2 horizon of the other three pedons. The Ae horizon, of silt loam texture, was a brown to yellowish brown (10YR 5/3 to 10YR 5/4) color in the natural state and dried to a light yellowish brown (10YR 6/4) color. The structure of the Ae horizon was very similar to the Ae_2 horizon of pedons 1, 2 and 3, being moderate to strong, fine to medium platy

which broke to a crumb structure. The Ae horizon was of very friable consistence and had a diffuse boundary.

Pedons 1 and 3 exhibited an AB transition of loam texture. The AB was a yellowish brown (10YR 5/4) color at the natural moisture content and dried to a light yellowish brown (10YR 6/4) color. The structure of the AB horizon in pedon 1 was weak, fine subangular blocky, which broke to coarse platy and granular. The AB horizon in pedon 3 was more Ae in character with a moderate coarse platy structure breaking to granular or crumb. Both pedons had a friable consistence in the AB horizon and diffuse boundaries.

The Bt horizon of pedons 2, 3, 4 and 5 was yellowish brown (10YR 5/4) in color under natural conditions, with pedon 1 having a light olive brown (2.5Y 5/4) color. All Bt horizons upon drying had a light yellowish brown (10YR 6/4) color and loam texture. The structure of Bt horizons was slightly variable from weak to moderate, fine to medium, subangular blocky, of friable consistence. These structures broke to a granular structure or in the case of pedon 1 to a granular to crumb structure. No cutanic features were observable on the subangular blocky peds but some of the granular structural units displayed what appeared to be discontinuous surface cutans. The rooting arrangement in the Bt horizon was variable. A very fine, random rooting system was observed with regard to the subangular blocky structure, occurring in both inped and exped positions with the amount ranging from very few to plentiful. Although these roots were inped and exped with respect to the subangular blocky structure, they were restricted to exped positions on the granular structure. The quantity of roots

diminished with increasing depth in the horizon. In addition a few fine and medium, random to oblique roots existed which were inped with respect to the granular structure.

Pore space within the Bt horizons consisted of many, very fine, discontinuous, inped, simple vesicular and dendritic interstitial pores. This pore space was inped with respect to the subangular blocky structure but inped and exped in consideration of the granular structure. The absence of dendritic interstitial pores in the Bt horizon of pedon 3 may be explained by the fact that this portion of the solum was water saturated at the time of sampling. This is in agreement with Sleeman's (1963) concepts of ped formation in clay soils from wetting and drying and associated swelling and shrinking.

The horizons designated as BC were variable in color from light olive brown to yellowish brown (2.5Y 5/4 to 10YR 5/4), under field conditions and dried to a pale brown or light yellowish brown (10YR 6/3 to 10YR 6/4) colored material of loam texture. The structure of horizons given BC designation varied from weak fine subangular blocky to strong subangular and angular blocky, which broke to a granular structure in the majority of cases. BC horizons were in all instances of friable consistence.

Site 2. The characteristic profile horizonation of the Hubalta Series investigated at Site 2 was L-H, Ae or (Ae_1, Ae_2), AB, Bt_1, Bt_2, BC, C, with parent material occurring at a depth of 28 to 37 inches.

The surface organic (L-H) horizon, variable from two to five inches in thickness, was composed predominantly of deciduous leaf litter

with some grasses, and exhibited partial decomposition in the lower portions. The relatively thin (2 to 3 inches) Ae_1 horizon, occurring in pedons 1, 2, 4 and 5 was variable in color from yellowish brown and grayish brown to pale brown (10YR 5/4 to 10YR 5/2 to 10YR 6/3), at the natural moisture content, and dried to light brownish gray, light gray and very pale brown (10YR 6/2 to 10YR 6/1 to 10YR 7/3) colors, respectively, with all Ae_1 horizons being of silt loam texture. The structure of the Ae_1 horizons was relatively uniform, varying from moderate to strong, fine to medium platy, of very friable consistence. The Ae_1 horizon in all cases had a clear, smooth boundary.

The Ae_2 horizon of pedons 1, 2, 4 and 5 and the Ae horizon of pedon 3 all possessed the same yellowish brown (10YR 5/4) color in the natural state, which dried to a pale brown or very pale brown (10YR 6/3 to 10YR 7/3) color. The Ae_2 horizons of pedons 1, 2 and 5 and the Ae horizon of pedon 3 were of silt loam texture and a clay loam texture was observed in the Ae_2 horizon of pedon 4. The structure of these horizons was variable from weak to strong, fine to medium platy with the exception of the Ae_2 horizon in pedon 4 which had a weak fine subangular blocky structure which broke to a weak medium platy structure. The consistence of these structural units is best described as friable in all cases. These horizons all had a clear smooth boundary.

The two to three inch thick AB transition, occurring in all pedons investigated, was variable from dark brown to yellowish brown (10YR 4/3 to 10YR 5/4) in the natural state, with each individual AB horizon differing by one unit of value or chroma. Upon drying the AB horizon had a uniform pale brown (10YR 6/3) color. The structure of

the AB horizon was variable from weak to moderate, fine to medium, subangular blocky with pedon 3 exhibiting a tendency to platy. The texture of the AB horizon was clay loam in four of the five pedons with a clay texture in pedon 4. The textural difference conforms to the higher clay content in the Ae_2 horizon of pedon 4 reported above. The consistency of the AB transition was friable in most cases or friable to firm in the moist conditions. The AB horizon boundary was in all cases diffuse.

The Bt_1 horizon consisted of dark yellowish brown to dark brown to brown (10YR 4/4 to 10YR 4/3) colored material of clay loam to clay texture which in the air-dry state exhibited a color variable from brown to pale brown (10YR 5/3 to 10YR 6/3). The structure of Bt_1 horizons ranged from strong fine, to strong medium, subangular blocky with the exception of pedon 5. The Bt_1 horizon in this pedon had a strong medium to coarse subangular blocky structure. The consistence was generally friable to firm with the exception of pedon 5 which was firm to very firm. Cutanic features were observable on vertical, horizontal and angular surfaces of peds and the presence of "slickensides" was noted in pedon 5. The network of roots was similar in the five Bt_1 horizons, with an abundance of very fine and a few coarse, randomly arranged exped roots. In addition pedons 3 and 5 had a random distribution of few to plentiful medium sized roots which were inped and exped in location.

Pore space in Bt_1 horizons of pedons 1, 2, 3 and 4 was relatively consistent with few to common, very fine, discontinuous, randomly arranged, inped simple tubular pores, with few common, micro, exped, interstitial dendritic pores. The Bt_1 horizon of pedon 5, which had

the larger and firmer subangular blocky structure, contained a larger abundance of smaller, discontinuous, random, inped, simple tubular pores and a lesser amount of micro, exped, interstitial, dendritic pores. In all cases the Bt_1 had diffuse horizon boundaries.

The natural color of the Bt_2 horizon was variable among the five pedons from dark brown to brown to very dark grayish brown (10YR 4/3 to 10YR 3/2), and dried to a brown or yellowish brown (10YR 5/3 to 10YR 5/4) color. The Bt_2 horizons were of clay loam to clay texture with pedons 4 and 5 again exhibiting a higher clay content. The structure of the Bt_2 horizon was variable with pedons 1, 2 and 3 having a moderate to strong, fine to medium, subangular blocky structure and pedons 4 and 5, a strong, medium to coarse, subangular blocky structure in the Bt_2 horizon. Consistence varied in the same manner as texture and structure, with pedons 1, 2 and 3 being friable to firm and pedons 4 and 5 firm to very firm. Cutanic features were observed on vertical, horizontal and angular structural surfaces, and the presence of "slickensides" was observed in the Bt_2 horizon of pedon 5.

Roots, exhibiting some degree of variability in abundance, size and arrangement existed in the Bt_2 horizons in all five pedons. Pedons 1 and 2 contained few to plentiful, very fine, random exped roots and very few, medium to coarse, random, exped roots. No inped roots of this size were noted in field observation in the Bt_2 horizon of any pedon. Pedons 3, 4 and 5 however contained a greater abundance of roots in the Bt_2, with plentiful to abundant, very fine, random, exped roots, with a few medium to coarse random roots, in both inped and exped positions.

Pore space within the Bt_2 horizon was relatively consistent, by all criteria used in evaluation, showing greatest variability in abundance. The pore space consisted of few to many, very fine to micro, discontinuous random, inped, simple tubular pores with few to common, micro, exped, interstitial, dendritic pores. The greatest abundance of micro sized pores were observed in pedon 5. The horizon boundary was in all cases diffuse.

The BC horizon was variable from an olive brown to dark brown (2.5Y 4/4 to 10YR 3/3) color at the natural moisture content. When dried the BC horizon displayed a light olive brown (2.5Y 5/4) color. The texture of the BC horizon followed the trend observed in the Bt_2 horizon, with pedons 1, 2 and 3 being of clay loam texture and pedons 4 and 5 of clay texture. The structure of the BC horizon varied from a moderate to strong, coarse blocky, to a massive structure. Pedon 4 had a moderate, fine, subangular blocky appearance and pedon 5 was best described as fragmental to massive. The consistence of the horizon is best defined as friable to firm or firm. All BC horizon boundaries were diffuse with the exception of pedon 4 which was characterized by a clear smooth boundary.

The C horizon of the five pedons was olive brown (2.5Y 4/4) in color, under natural conditions, and upon drying altered to a light olive brown (2.5Y 5/4) color. The texture was, in most cases, clay loam with the exception of pedon 4 of clay texture. The C horizon in each pedon examined was mottled with a great deal of variability in abundance, size and color of mottles. The parent material was massive to fragmental in structure, with consistence variable from friable to

firm.

Site 3. The five pedons examined at Site 3 were classified as two classes at the series level of abstraction. Pedons 1, 2, 3 and 4 are best classified as the Hubalta Series with pedon 5 being of the Bremay Series (A. Twardy, personal communication). The differentiation between the two series is made on the basis of drainage and associated mottling. The Hubalta Series is well drained and the Bremay Series imperfectly drained. The characteristic horizonation sequence in pedons 1 to 4 was L-F, Ah, Ae, AB, Bt_1, Bt_2, Bt_3, BC, and C. The horizonation sequence of pedon 5 was L-F, Ah, Aegj, ABgj, $Btgj_1$, $Btgj_2$, $Btgj_3$, BCgj and Cg. The distinguishing feature which separated the soils into two series was that pedon 5 was heavily mottled at all depths below two inches while the remaining four pedons showed little mottling. A description of mottling in pedon 5 is presented in page A15 of the Appendix. Parent material in these pedons occurred at a mean depth of 40 inches.

The surface organic (L-F) horizon, from two to three inches in thickness, consisted of partially decomposed organic matter, of which mosses predominated. The relatively thin (1 to 2 inches) Ah horizon in pedons 1 to 4 was a very dark brown (10YR 2/2) color, under natural moisture conditions with the Ah horizon of pedon 5 being black (10YR 2/1) in color. Upon drying all five Ah horizons exhibited a very dark grayish brown (10YR 3/2) color. The texture of the Ah horizon in the first four pedons was silt loam. The Ah horizon of pedon 5 was of a silty clay loam texture. All five horizons were granular to massive in structure and very friable in consistence, with an abrupt smooth boundary.

The relatively thin (2 to 5 inch) Ae horizon, in the five

pedons examined, was extremely variable in color. The range of variability extended from dark brown to brown (10YR 4/3), to dark grayish brown (10YR 4/2), to grayish brown (10YR 5/2) in the natural condition. Upon drying these horizons had light gray (10YR 7/1), light grayish brown (10YR 6/2), and light gray (10YR 7/2) colors, respectively. The texture of the Ae horizons ranged from silt loam to loam. Pedon 4 was an exception being of silt loam to sandy loam texture. In all cases examined the Ae horizon had a weak fine platy structure, of friable consistence and showed an abrupt smooth boundary.

An AB transition, from 2½ to 4½ inches thick, existed in all five pedons. The color of the AB horizon varied from brown (10YR 5/3), dark brown to brown (10YR 4/3), to dark grayish brown (10YR 4/2) at the natural moisture content. Upon drying the soil changed to light brownish gray to brown (10YR 6/2 to 10YR 5/3) colors. Texturally the pedons varied from a clay texture in the AB horizon of pedon 1 to a clay loam texture in pedons 2 and 3 and a silt loam texture in pedons 4 and 5. All of the AB horizons were of weak fine subangular blocky structure and firm consistence, with a clear smooth boundary.

The horizon designated Bt_1 in field observation was dark grayish brown to brown (10YR 4/2 to 10YR 5/3) in color, at the natural field moisture content, and dried to a grayish brown to pale brown (10YR 5/2 to 10YR 6/3) color. With the exception of pedon 4, which had a clay loam texture, all other Bt_1 horizons were of clay texture. Moderate fine subangular blocky structure and firm consistence was observed in all five of these horizons investigated. Cutanic surfaces were observed only occasionally on vertical and horizontal surfaces of peds in this

horizon.

The arrangement of roots was relatively constant through the five pedons with the observed features including few, micro to very fine, horizontal, exped roots, with very few to few, fine to medium, vertical inped roots. Pores in the Bt_1 horizon were common to many in quantity, micro in size, and exped, interstitial, dendritic in nature. Inped tubular pores were non existent in the five pedons examined. The boundary of the Bt_1 horizon was, in all cases, clear and smooth.

The Bt_2 horizons in the pedons at Site 3 varied from dark gray, to very dark grayish brown, to brown to dark brown (10YR 4/1 to 10YR 3/2 to 10YR 4/3) at field moisture content and changed to grayish brown, to brown (10YR 5/2 to 10YR 5/3) colors upon drying. All of the Bt_2 horizons examined were of clay texture with a strong, fine subangular blocky structure of firm consistence. Cutanic surfaces were observed on vertical, horizontal and angular ped surfaces. As was the case in the horizon designated Bt_1, the arrangement of roots and the amounts were relatively constant through the five pedons. The rooting habit consisted of few, micro to very fine, horizontal, exped roots; with very few, fine to medium, vertical, inped roots. The pore space of the Bt_2 horizon was characterized as common, micro, exped, interstitial, dendritic pores, very similar to pore space in Bt_1 horizons. As was the case in the Bt_1 horizon, inped tubular pores were non existent by field observation. The horizon boundary is all cases was clear and smooth.

The Bt_3 horizons of these pedons showed lesser variation in color than the above horizons, ranging from a dark brown to brown, to dark grayish brown (10YR 4/3 to 10YR 4/2) at field moisture content

and brown to grayish brown (10YR 5/3 to 10YR 5/2) upon drying. This horizon was, by all analyses, of clay texture and strong medium subangular blocky structure of firm consistence. Cutanic features were observed as vertical, horizontal and angular surfaces within this horizon in all five pedons.

The rooting arrangement was, as before, relatively uniform among the five pedons in the Bt_3 horizon. The pattern of roots consisted of few, micro to fine, horizontal exped roots, with very few vertical, inped roots, which ranged in size from micro to medium. Pore space was characterized by common, micro, exped, interstitial, dendritic pores with no inped, tubular pores, which was similar to observations made in the Bt_1 and Bt_2 horizons. The Bt_3 horizon in all cases possessed a clear smooth boundary.

The BC horizon varied from a dark grayish brown to olive brown (2.5Y 4/2 to 2.5Y 4/4) color in the natural condition and when dried altered to a grayish brown (2.5Y 5/2) color in all cases. The most frequently observed texture of the BC horizon was clay, with pedon 1 having a clay loam to clay texture. The BC horizon possessed, in all cases, a weak, medium to coarse, subangular blocky structure of firm to friable consistence with clear smooth boundaries.

The C horizon was dark grayish brown to very dark grayish brown to olive brown (2.5Y 4/2 to 2.5Y 3/2 to 2.5Y 4/4) in color at field moisture conditions, and dried to a grayish brown (2.5Y 5/2) color and clay loam or clay texture. The parent material of these pedons was massive in structure and of friable consistence.

B. Laboratory Studies

Analyses as described in the "Materials and Methods" section were conducted on samples taken from each horizon in each pedon. These analyses were undertaken to assist in the characterization of each pedon and to evaluate the variability among selected pedons at each site. In addition, studies of the variation in components with depth may be used to elucidate processes operative in the development of fabrics within a site and for comparison among different sites. Results of individual analyses or mean values of analyses done in duplicate or triplicate are reported in the Appendix.

In an attempt to establish a "mean value" for pedons at each site, the means of analyses with an estimate of variability for the five individual pedons are reported on the following pages. In the case of moisture content and bulk density, the number of samples used, with the exception of the Bt horizon at Site 1 was fifteen, from three replicates in each of five pedons. In this instance the "Students t Distribution" was used to establish 95 percent confidence limits. In the remainder of the analyses presented, the number of samples employed was generally five. Reported with the mean is the mean deviation in an attempt to present a comparable indication of variability. Soil reaction is reported as the range of pH values obtained from horizons of different pedons at each site.

1. Physical Analyses

(a) Natural Moisture Content and Bulk Density

Mean values and 95 percent confidence limits for natural

moisture content and bulk density at the time of sampling are reported in Table 2 for the three sites.

The moisture content in pedons at Site 1 was higher in the Ae horizon(s) than the Bt horizon with relatively large 95 percent confidence limits indicating considerable variability in the entire solum. Pedons at Site 2 had a low moisture content in the Ae horizon(s) with the greatest variability observed throughout the profile. The Bt_1 horizon had the highest moisture content in the natural state and the least variability. A slight decrease in natural moisture occurred in the Bt_2 and an additional decrease in the C horizon.

Site 3 was characterized by a relatively uniform distribution of natural moisture. The moisture content of the Ae horizon(s) was again the most variable with the 95 percent confidence limits being a range of five percent. The moisture content increased slightly in the Bt_1 horizon and decreased to the C where an increase was observed.

In all soils analysed bulk density increased with depth in the pedon. The lowest corrected bulk density value reported is for the Ae horizon(s) in pedons at Site 1. A mean value of 1.20 gm/cc with a 95 percent confidence range from 1.14 to 1.26 gm/cc was obtained for these horizons indicating considerable variability. The Bt horizons at Site 1 had a mean corrected bulk density of 1.37 gm/cc and confidence limits from 1.24 to 1.50 gm/cc. The mean value for these Bt horizons is well within the limits obtained for Ae horizons at the other two sites. In addition the bulk density of the Bt horizons at Site 1, as measured by the "balloon method" has the greatest variability of all density analyses done. Site 1 also has the greatest

TABLE 2 MEAN VALUES, STANDARD DEVIATIONS AND 95% CONFIDENCE LIMITS FOR MOISTURE CONTENT, BULK DENSITY AND CORRECTED BULK DENSITY FOR SITES 1, 2, & 3

Hor.	% Natural Moisture	S.D.	95% Lower Limit	95% Upper Limit	(gm/cc) Bulk Density	S.D.	95% Lower Limit	95% Upper Limit	(gm/cc) Corr. Bulk Density	S.D.	95% Lower Limit	95% Upper Limit
						Site 1						
Ae	24.7	4.17	22.4	27.0	1.27	0.0871	1.22	1.32	1.20	0.110	1.14	1.26
Bt	20.2	2.35	17.3	23.1	1.46	0.0942	1.34	1.58	1.37	0.103	1.24	1.50
						Site 2						
Ae	19.1	2.88	17.5	20.7	1.37	0.0614	1.34	1.40	1.36	0.0556	1.33	1.39
Bt_1	22.8	0.94	22.3	23.3	1.49	0.0558	1.46	1.52	1.48	0.0548	1.45	1.51
Bt_2	22.2	1.14	21.6	22.8	1.53	0.0614	1.50	1.56	1.52	0.0632	1.49	1.55
C	19.4	1.25	18.7	20.1	1.70	0.0373	1.68	1.72	1.68	0.0402	1.66	1.70
						Site 3						
Ae	23.3	4.44	20.8	25.8	1.37	0.129	1.30	1.44	1.36	0.130	1.29	1.43
Bt_1	23.9	1.50	23.1	24.7	1.50	0.0347	1.48	1.52	1.50	0.0364	1.48	1.52
Bt_2	23.0	2.48	21.6	24.4	1.53	0.0678	1.49	1.57	1.52	0.0673	1.48	1.56
Bt_3	22.3	2.35	21.0	23.6	1.57	0.0661	1.53	1.61	1.56	0.0710	1.52	1.60
C	22.9	2.76	21.4	24.4	1.57	0.0739	1.53	1.61	1.56	0.0762	1.52	1.60

difference between bulk density and corrected bulk density due to the comparatively high content of coarse fragments.

Pedons at Site 2 had a mean corrected bulk density value of 1.36 gm/cc in the Ae horizon(s) and relatively small 95 percent confidence limits. The bulk density increased in the Bt_1 horizon and remained relatively constant to the C horizon where a density increase was again observed. Pedons at Site 3 had a mean corrected bulk density value of 1.36 gm/cc in the Ae horizon which increased to a mean of 1.50 gm/cc in the Bt_1 horizon. A gradual increase in density was measured to the parent material.

The generally observed trend of increasing bulk density with depth was attributed by Buckman and Brady (1968) to decreasing organic matter content with depth and consolidation due to overburden stress.

(b) Particle Size Analysis

Mean values and corresponding mean deviations obtained for particle size distribution in pedons sampled at the three sites are reported in Tables 3, 4 and 5. Percentages of sand, silt, coarse clay and fine clay are based on the oven-dry weight of salt-free, organic matter-free and carbonate-free, less than 2 mm, fine earth fraction.

The sand fraction in the pedons analysed at Site 1 was least in the Ae portion of the solum and increased to the BC horizon with mean deviations in the range of 3 to 5 percent. Sites 2 and 3 had an opposite trend with greater amounts of sand in the Ae decreasing through the B horizons and slightly increased values in the parent material. St. Arnaud and Whiteside (1963) attribute the lower proportion of sand in soil horizons, as observed for soils of the Coalspur Series, to a

TABLE 3 MEAN VALUES FOR PARTICLE SIZE DISTRIBUTION, SILT TO CLAY RATIO, AND FINE CLAY TO COARSE CLAY RATIO WITH MEAN DEVIATIONS IN PEDONS AT SITE 1

Hor.	% Sand	M.D.	% Silt	M.D.	% Clay	M.D.	Si/C	M.D.	FC/CC	M.D.
Ae_1*	37	2.0	49	0.43	14	1.8	3.7	0.53	0.57	0.14
Ae**	34	0.0	55	0.00	11	0.0	5.0	0.00	0.30	0.080
Ae_2*	33	2.0	54	3.3	13	1.3	4.3	0.76	0.45	0.15
Bt	42	2.9	36	1.7	22	1.4	1.6	0.12	0.58	0.078
BC	45	2.9	35	1.1	20	2.2	2.1	0.60	0.63	0.32

* Values reported for Ae_1 and Ae_2 horizons in pedons 1, 2 and 3

** Values reported for Ae horizons in pedons 4 and 5

TABLE 4 MEAN VALUES FOR PARTICLE SIZE DISTRIBUTION, SILT TO CLAY RATIO, AND FINE CLAY TO COARSE CLAY RATIO WITH MEAN DEVIATIONS IN PEDONS AT SITE 2

Hor.	% Sand	M.D.	% Silt	M.D.	% Clay	M.D.	Si/C	M.D.	FC/CC	M.D.
Ae_1	39	4.5	52	1.8	9.3	2.8	6.2	1.6	0.40	0.055
Ae_2	33	4.6	43	4.5	24	6.6	2.5	1.4	1.7	1.8
AB	29	3.1	36	2.3	36	3.8	1.3	0.39	1.4	1.1
Bt_1	28	5.1	32	1.1	41	4.1	0.94	0.22	2.1	1.5
Bt_2	29	4.4	31	1.9	40	4.5	0.98	0.29	1.5	0.66
BC	29	3.8	32	1.5	39	2.6	1.1	0.34	1.3	0.59
C	31	4.3	33	1.3	36	3.4	1.2	0.37	0.92	0.23

TABLE 5 MEAN VALUES FOR PARTICLE SIZE DISTRIBUTION, SILT TO CLAY RATIO, AND FINE CLAY TO COARSE CLAY RATIO WITH MEAN DEVIATIONS IN PEDONS AT SITE 3

Hor.	% Sand	M.D.	% Silt	M.D.	% Clay	M.D.	Si/C	M.D.	FC/CC	M.D.
Ah	26	3.6	51	2.7	23	5.3	2.5	0.70	0.83	0.13
Ae	35	4.1	51	6.2	14	7.4	4.1	2.4	0.60	0.19
AB	31	4.1	33	2.2	35	5.1	1.2	0.52	1.7	1.1
Bt_1	29	2.6	29	2.0	42	2.8	0.92	0.43	1.9	0.81
Bt_2	26	1.4	29	1.0	45	0.40	0.82	0.31	2.4	1.3
Bt_3	27	1.2	30	0.32	43	1.4	0.90	0.28	2.8	1.5
BC	28	1.1	30	0.64	42	1.0	0.92	0.31	2.5	1.2
C	28	1.4	31	0.48	41	1.0	0.94	0.30	2.7	1.6

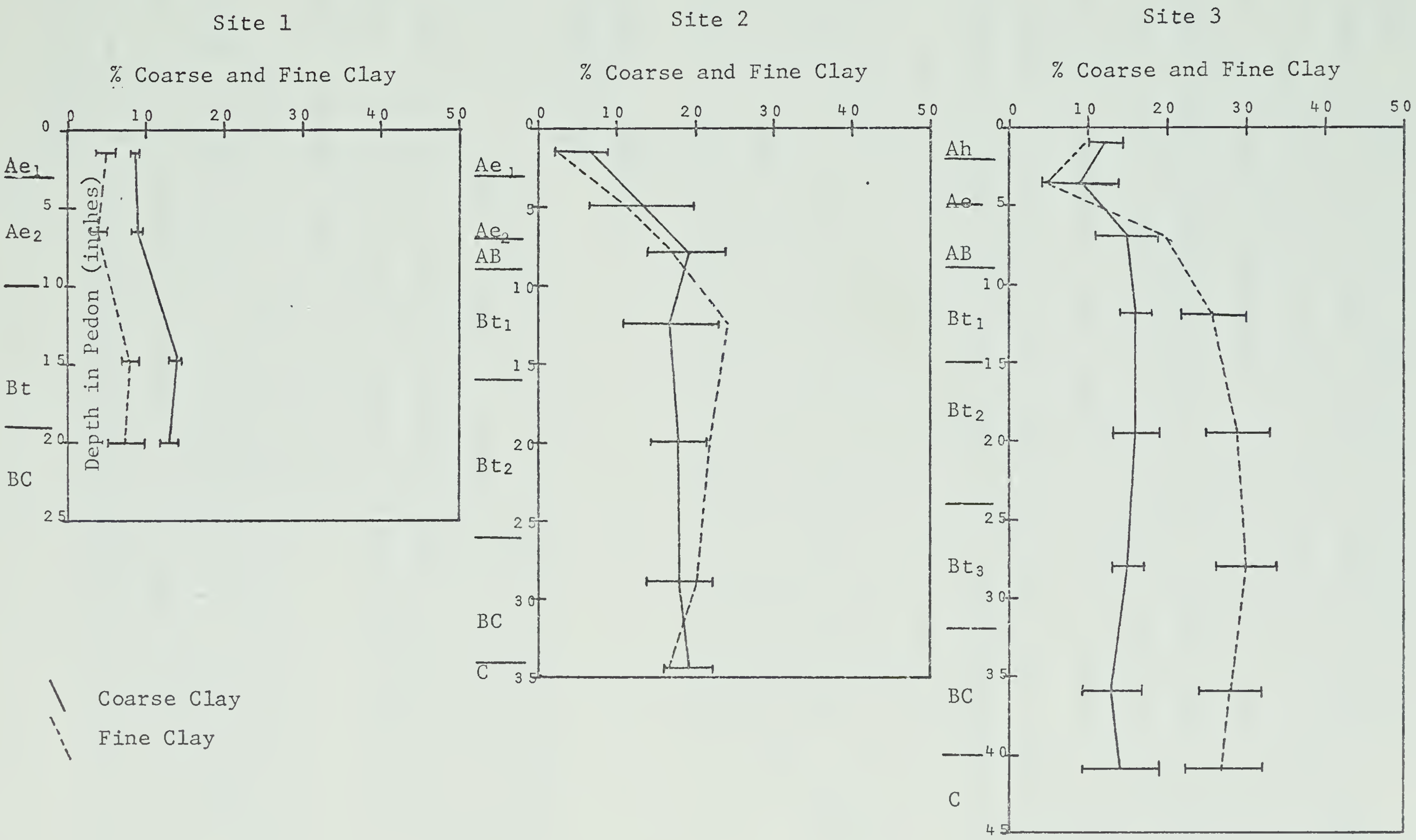
combination of chemical and physical disintegration *in situ*. They reported that such disintegration is rarely a purely physical process since some chemical alteration can generally be detected. The low sand content of the Ae horizons may perhaps be attributed to loess. Large areas of local loess deposits have been reported by Dumanski (1970) near the sampling site.

The percentage of silt size particles at Site 1 is an approximate inverse of the observed sand distribution in the pedons, having highest values in the Ae and decreasing in value at greater depths in the solum. Sites 2 and 3 have a similar trend with relatively small mean deviations below the AB transition horizon.

The percentage of coarse clay plotted with respect to depth in the pedon in Figure 6, shows a comparatively large increase in the Bt horizon and a slight decrease in the BC horizons of Site 1. Pedons at Site 2, as reported in Figure 6, have an increasing coarse clay content through the Ae horizon(s) which reaches a maximum in the AB transition. This value remains relatively constant through the remainder of the solum to the parent material. The coarse clay content of pedons at Site 3 increases through the Ae and AB horizons reaching a maximum in the Bt_1 horizon as shown in Figure 6. A gradual decrease in clay content is observed to the parent material.

The percentage of fine clay compared to depth reaches a maximum in the Bt horizon in pedons at Site 1, in the Bt_1 horizon in pedons at Site 2, and in the Bt_2 horizon in pedons at Site 3. These data accompanied by fine clay to coarse clay ratios, and the silt to clay ratios, in Tables 3, 4 and 5, are indicative of fine clay transported from the A horizons and deposited in the B horizon to a greater extent than coarse clay in pedons sampled at Sites 2 and 3, or a form of differential

FIGURE 6. MEAN VALUES AND MEAN DEVIATIONS OF COARSE AND FINE CLAY PARTICLE SIZES IN PEDONS AT THREE SAMPLING SITES



lessivage. Pedons at Site 1 show similar proportions of fine and coarse clay in each horizon. Trends as observed in pedons at Sites 2 and 3, suggesting greater removal of fine than coarse clay from Ae horizons and subsequent deposition in the B horizon have been reported by Pawluk (1961) and Harpstead and Rust (1964). Pawluk (1960) proposed that coarse clay is removed from the Ae horizon by eluviation in the process of weathering to a fine clay size. This is in agreement with the proposal of Bartelli and Odell (1960), that finer clays would be more mobile and have a more active part in the clay translocation process.

The Ah horizon in pedons at Site 3 do not conform to the general pattern of particle size distribution, established in plotting percentage of a particular grain size with depth in the pedon. The Ah horizon has a higher fine clay and coarse clay content than the Ae horizons, a lower sand content and an equivalent silt content.

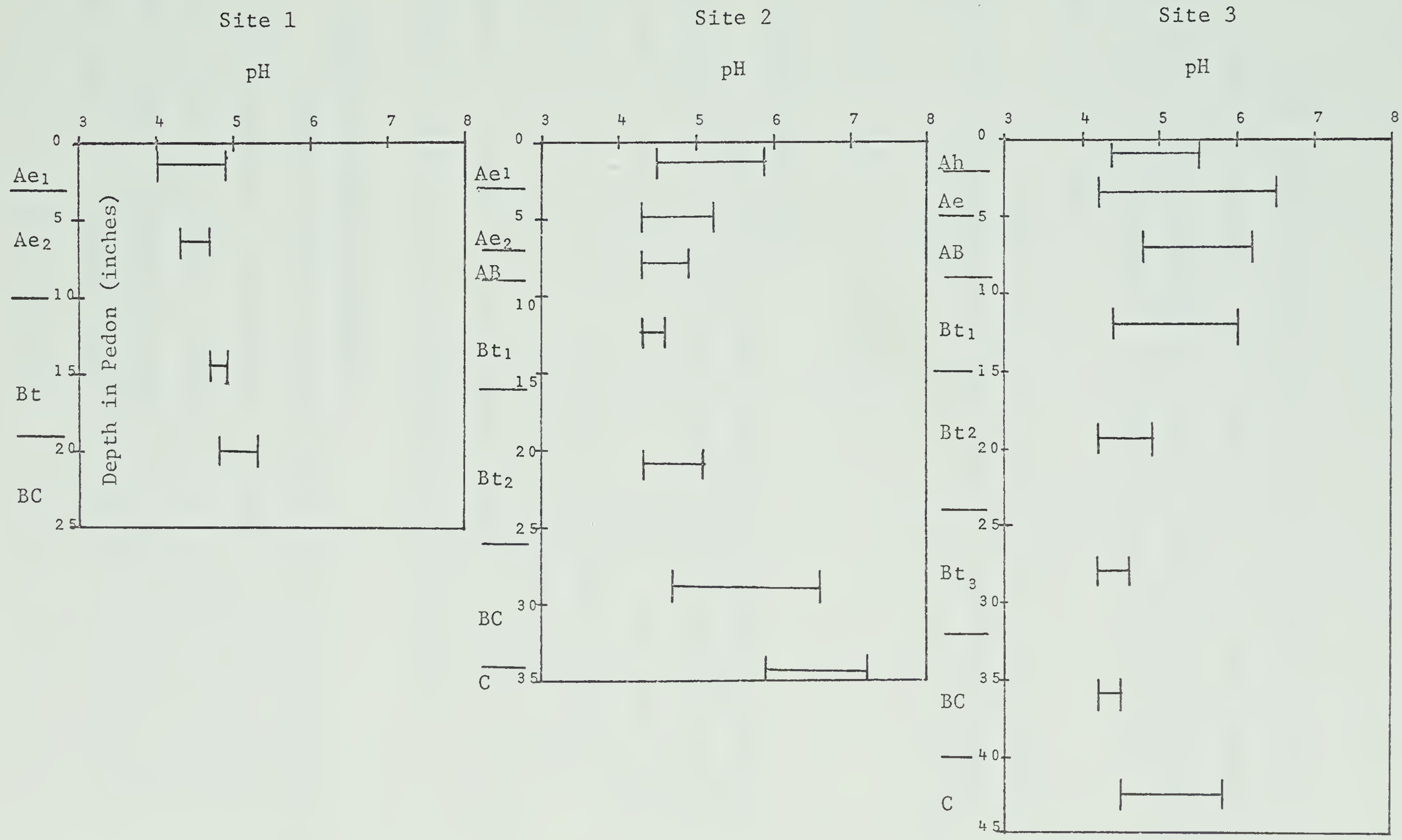
2. Chemical Analysis

(a) Soil Reaction

A plot of the range of pH values obtained for the five pedons at each site is shown in Figure 7. Pedons at Site 1 were acidic throughout, with the lowest values and the greatest range occurring in the Ae horizons. pH values increased slightly with increasing depth in the pedon but remained acidic in the BC horizon.

Pedons at Site 2 had a decreasing pH value from the wide range of acidic values in the Ae_1, to a minimum value with a narrow range in the Bt_1 horizon. Individual pH values and the range increased to the parent material where pH values bordered on neutral to alkaline reaction in the C horizon.

FIGURE 7. RANGE OF pH VALUES BY HORIZON IN PEDONS SAMPLED AT SITES 1, 2 AND 3



The range of pH values for horizons in pedons at Site 3 had a similar pattern to those at Site 2, but had an acid reaction throughout. Lowest pH values and narrowest ranges were observed in the Bt_2, Bt_3 and BC horizons. The parent material had an acidic reaction in all cases.

Data for Sites 2 and 3, but not for Site 1 are in agreement with results obtained by Pawluk (1961) and St. Arnaud and Whiteside (1964), who reported that Bt horizons in similar soils are usually the most acidic of the mineral horizons.

(b) Carbon and Nitrogen

Data presented in Table 6 indicate a continual decrease in carbon and nitrogen as well as the C/N ratio with increasing depth in the pedon for soils examined at Site 1. Similar trends were observed for soils at Sites 2 and 3, in agreement with organic carbon and nitrogen data presented by St. Arnaud and Whiteside (1964). The increasing C/N ratio in the B horizons of pedons at Sites 2 and 3 does not agree with the C/N ratio presented by these researchers.

(c) Sums of Exchangeable Cations

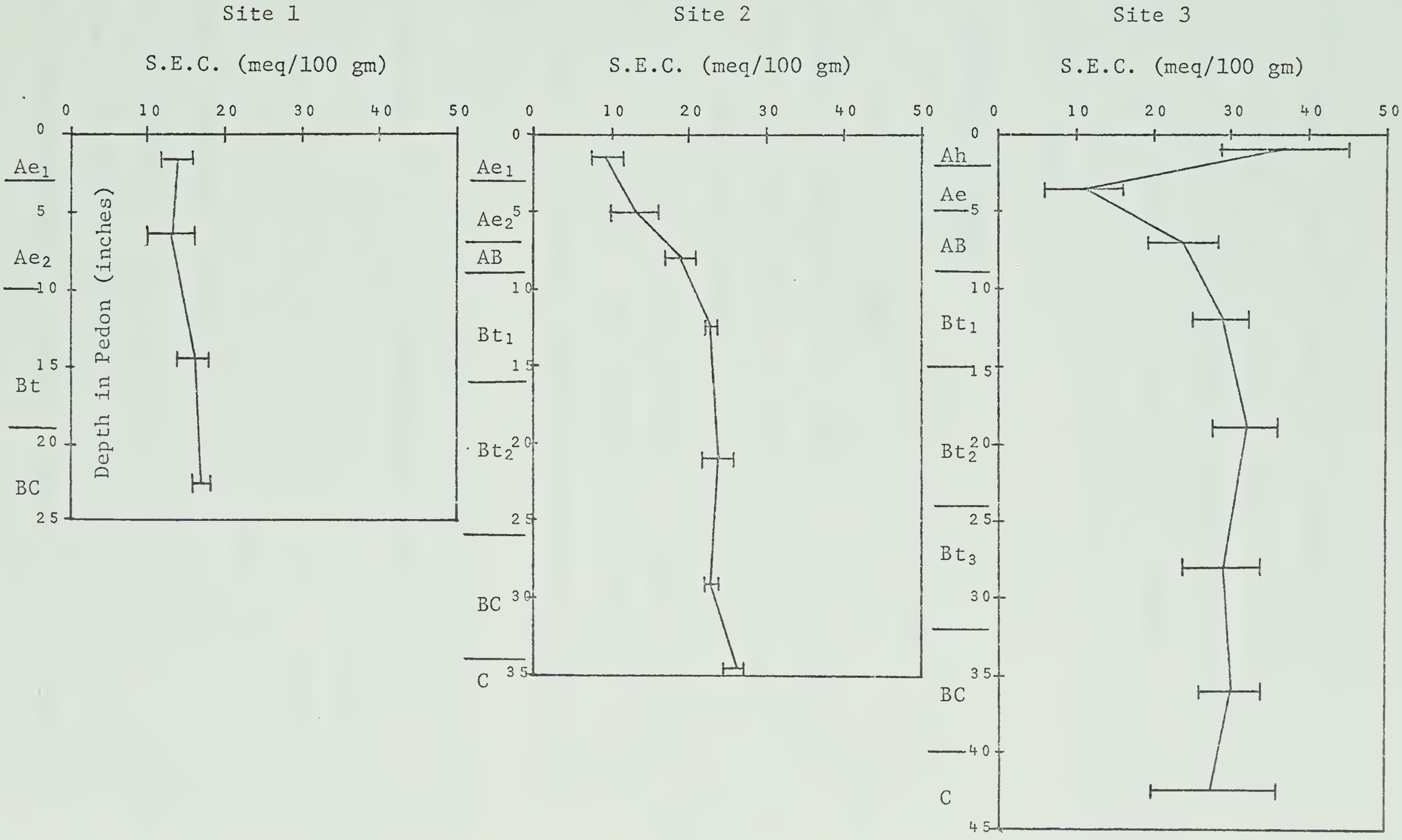
Exchange capacity, estimated from the sum of exchangeable cations, is clearly related to the amounts of colloidal and organic materials present in all soils studied, as proposed by St. Arnaud and Whiteside (1964). Sums of exchangeable cations with respect to depth in the pedon, presented in Figure 8, correlate well with the percentage of

TABLE 6

MEAN VALUES AND MEAN DEVIATIONS FOR TOTAL CARBON, NITROGEN AND C/N RATIOS FOR PEDONS SAMPLED AT THREE SITES

Hor.	% C Total	M.D.	% N	M.D.	C/N	M.D.
Site 1						
Ae_1	1.9	0.32	0.10	0.011	19	1.1
Ae	0.50	0.095	0.045	0.0050	11	0.90
Ae_2	0.78	0.20	0.063	0.011	12	1.6
Bt	0.23	0.030	0.030	0.00	7.6	1.0
BC	0.17	0.018	0.028	0.0032	6.3	1.5
Site 2						
Ae_1	1.2	0.32	0.090	0.015	13	1.1
Ae_2	0.76	0.10	0.074	0.0088	10	0.84
AB	0.72	0.059	0.070	0.0040	10	0.90
Bt_1	0.64	0.11	0.052	0.0064	12	1.6
Bt_2	0.60	0.084	0.046	0.0048	13	1.7
BC	0.69	0.13	0.048	0.0064	14	1.7
C	0.77	0.094	0.042	0.0032	18	1.4
Site 3						
Ah	6.0	1.5	0.48	0.096	12	0.66
Ae	0.67	0.088	0.062	0.0064	11	1.1
AB	0.64	0.13	0.058	0.010	11	1.0
Bt_1	0.59	0.045	0.050	0.00	12	0.90
Bt_2	0.57	0.042	0.042	0.0032	14	1.5
Bt_3	0.54	0.040	0.040	0.00	14	0.98
BC	0.50	0.039	0.038	0.0032	13	0.19
C	0.50	0.018	0.034	0.0048	15	1.5

FIGURE 8. MEAN VALUES AND MEAN DEVIATIONS FOR THE SUM OF EXCHANGEABLE CATIONS IN PEDONS AT SITES 1, 2 AND 3



fine clay data, presented in Figure 6, throughout the solum. The BC horizons in pedons at Site 1 and the C horizons in pedons at Sites 2 and 3 show a trend to greater amounts of exchangeable cations and a decrease in the content of fine clay. The Ah horizons at Site 3 have a very high sum of exchangeable cations which may be attributed to the high organic matter content.

(d) Exchangeable Cations

Mean values and mean deviations for exchangeable cations in terms of quantity (meq/100 gms) are presented in Table 7. The amount of exchangeable hydrogen decreases rapidly with increasing depth in the pedon for samples analysed from Site 1 similar to reported trends observed by Harpstead and Rust (1964). Pedons at Sites 2 and 3 increase in exchangeable hydrogen to the Bt_1 and Bt_3 horizons respectively, and then decrease with depth. The distribution of exchangeable acidity is, as would be anticipated, inversely proportional to the pH values reported in Figure 7.

Figures 9, 10, and 11 present exchangeable cation data based on a percentage of the sum of exchangeable cations for Sites 1, 2 and 3, respectively. Calcium is the dominant cation on the exchange complex of all pedons studied, as reported by Twardy (1969). Magnesium is in lesser proportion in the upper part of the solum, increases in the B horizons, and remains relatively equal through the transition horizon to the parent material. The larger proportion of calcium to magnesium as shown in Figures 9, 10 and 11 and by the Ca/Mg ratio presented in Table 7 may be attributed to decaying vegetation in the surface L-H

TABLE 7. EXCHANGEABLE CATIONS IN SELECTED PEDONS AT THREE SITES

Hor.	H Meq/100g	M.D.	Na Meq/100g	M.D.	K Meq/100g	M.D.
			Site 1			
Ae_1	5.9	1.7	0.20	0.067	0.39	0.017
Ae	3.2	0.11	0.085	0.025	0.23	0.010
Ae_2	3.9	0.68	0.10	0.033	0.29	0.073
Bt	2.5	0.12	0.12	0.0064	0.36	0.010
BC	2.0	0.068	0.15	0.038	0.35	0.014
			Site 2			
Ae_1	2.1	0.79	0.068	0.0075	0.24	0.046
Ae_2	3.5	0.68	0.052	0.018	0.31	0.066
AB	4.4	1.1	0.11	0.038	0.34	0.048
Bt_1	4.7	0.27	0.13	0.022	0.37	0.084
Bt_2	3.9	0.61	0.16	0.033	0.37	0.031
BC	1.3	1.0	0.16	0.030	0.33	0.031
C	0.32	0.23	0.16	0.022	0.33	0.042
			Site 3			
Ah	10	4.9	0.34	0.041	1.2	0.41
Ae	1.9	0.63	0.032	0.0064	0.38	0.14
AB	2.2	0.77	0.048	0.018	0.54	0.084
Bt_1	3.1	1.0	0.088	0.018	0.62	0.11
Bt_2	4.3	1.0	0.13	0.037	0.62	0.10
Bt_3	4.8	0.78	0.15	0.034	0.51	0.10
BC	4.5	0.52	0.18	0.037	0.49	0.067
C	2.4	0.68	0.16	0.058	0.43	0.085

Ca Meq/100g	M.D.	Mg Meq/100g	M.D.	Ca/Mg
Site 1				
6.2	0.42	1.4	0.19	4.4
5.5	0.16	1.3	0.0050	4.2
7.1	1.7	1.3	0.17	5.5
12	0.54	3.1	0.22	3.8
12	0.98	2.9	0.23	4.1
Site 2				
5.6	2.5	1.2	0.19	4.7
6.8	2.6	2.3	0.74	3.0
10	1.2	3.8	0.47	2.6
13	1.3	5.0	0.39	2.6
14	1.5	5.6	0.30	2.5
16	0.73	5.7	0.17	2.8
19	1.4	5.7	0.47	3.3
Site 3				
23	8.8	2.2	0.23	10.5
7.5	4.9	1.2	0.64	6.3
17	4.2	4.3	0.85	4.0
20	4.4	5.7	0.51	3.5
20	4.8	6.1	0.28	3.3
18	5.0	5.8	0.62	3.1
19	4.4	6.1	0.28	3.1
19	7.0	6.0	1.2	3.2

FIGURE 9. MEAN VALUES AND MEAN DEVIATIONS FOR EXCHANGEABLE CATIONS AS A PERCENTAGE OF THE SUM OF EXCHANGEABLE CATIONS AT SITE 1

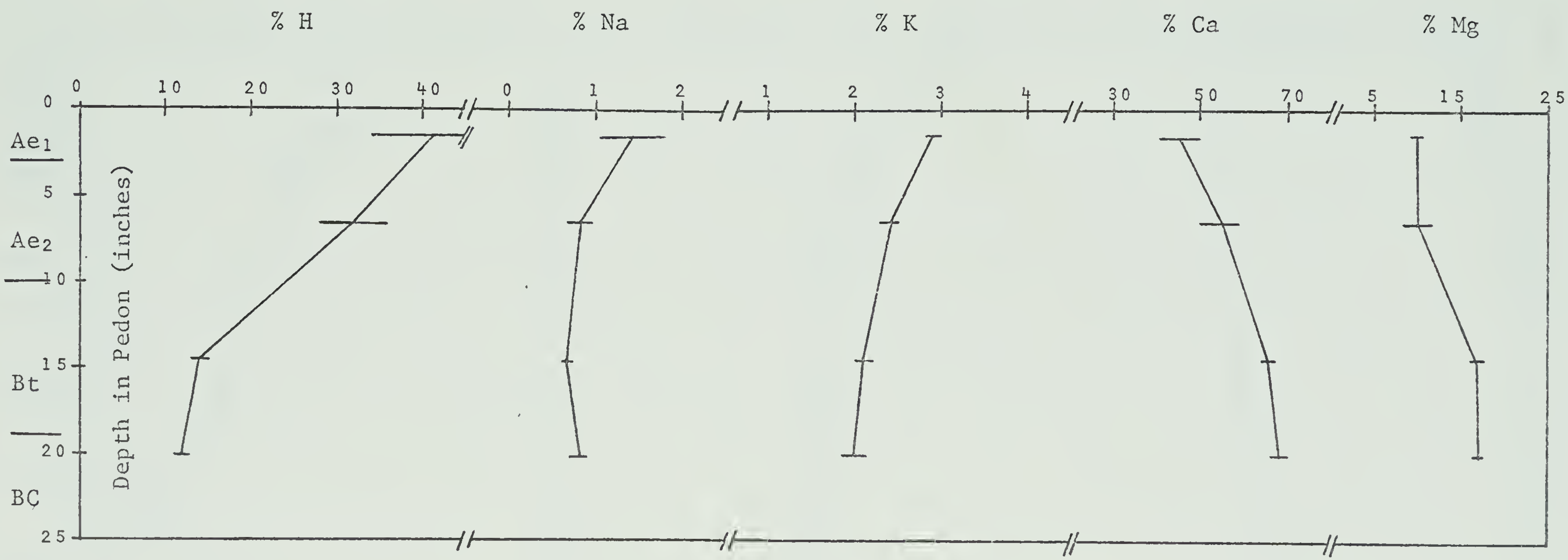


FIGURE 10. MEAN VALUES AND MEAN DEVIATIONS FOR EXCHANGEABLE CATIONS AS A PERCENTAGE OF THE SUM OF EXCHANGEABLE CATIONS AT SITE 2

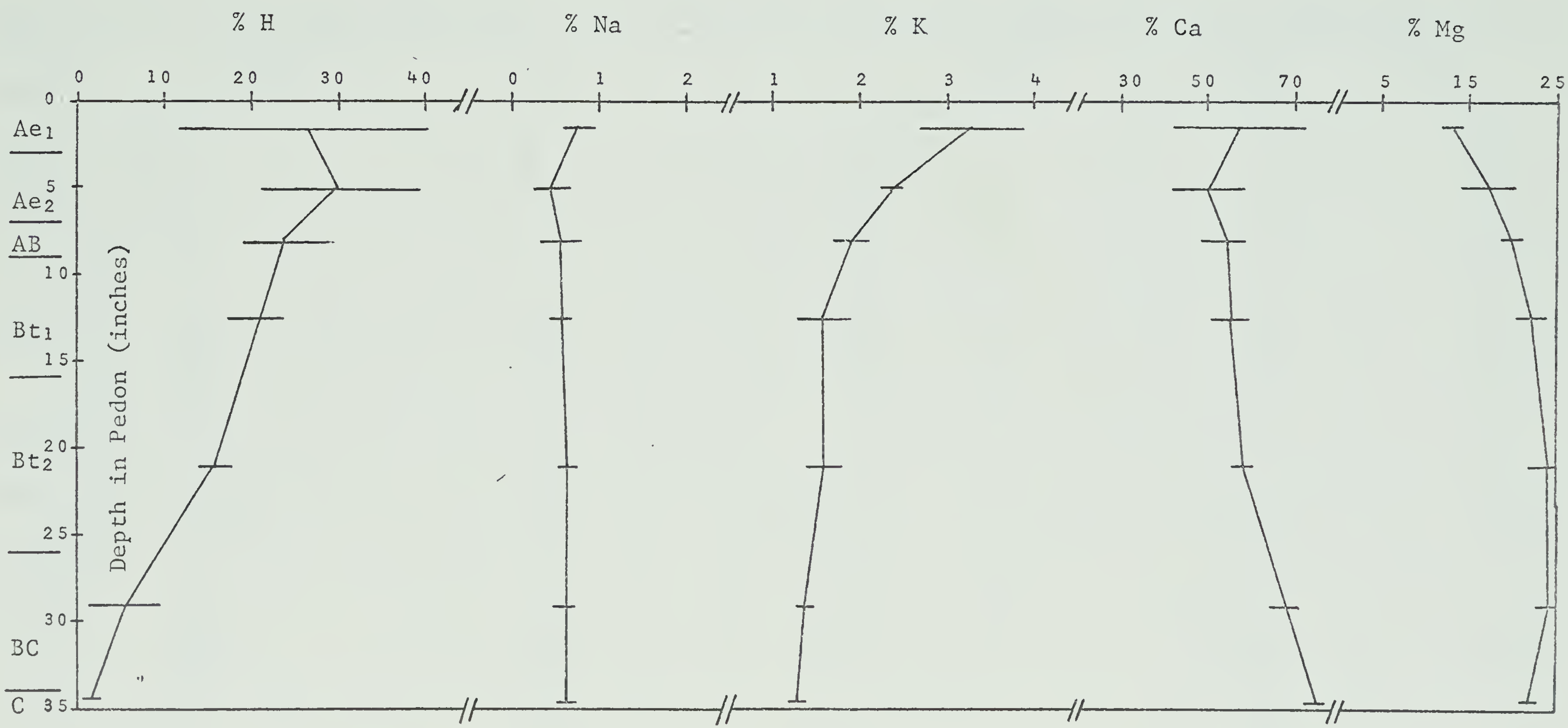
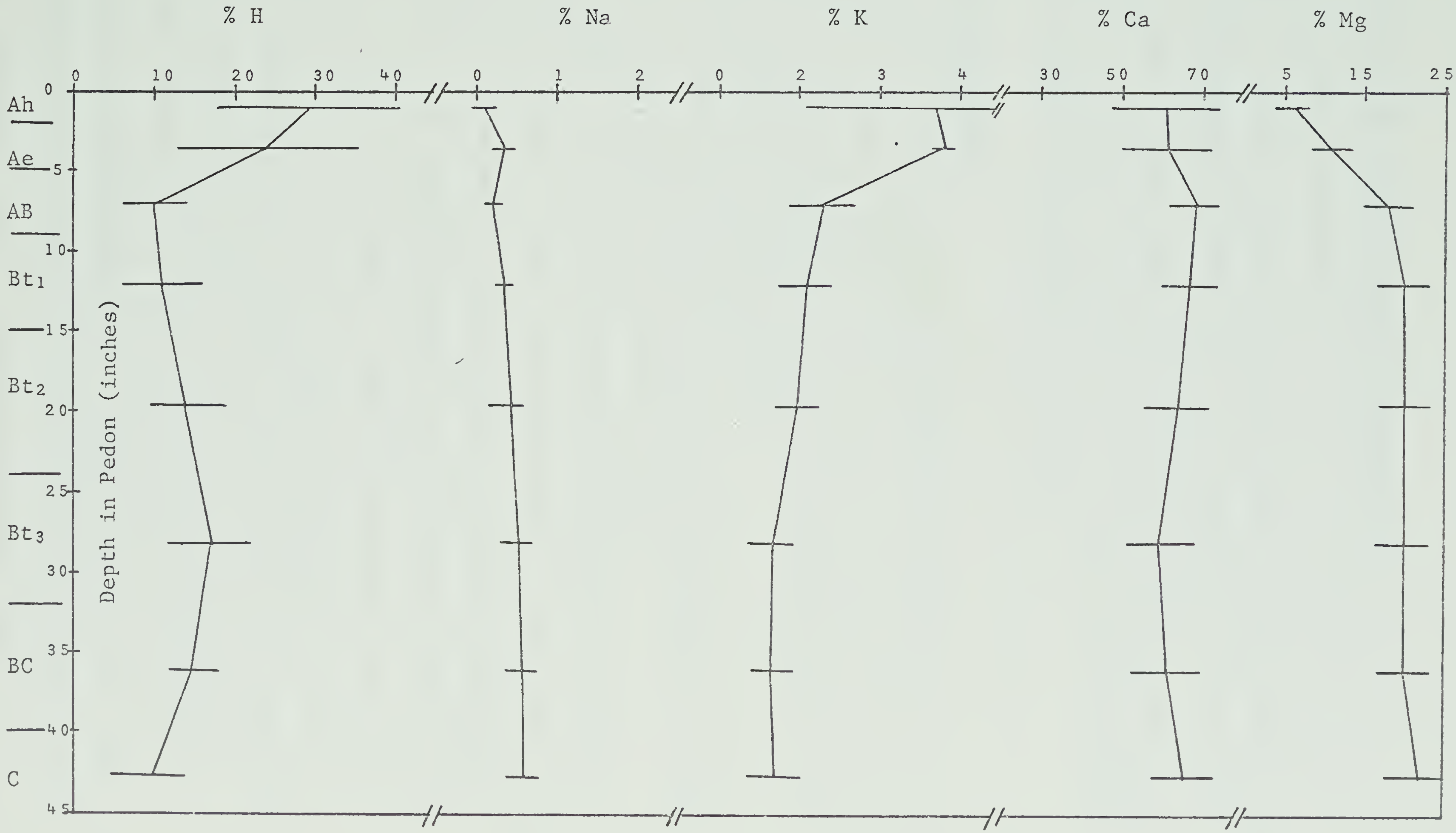


FIGURE 11. MEAN VALUES AND MEAN DEVIATIONS FOR EXCHANGEABLE CATIONS AS A PERCENTAGE OF THE SUM OF EXCHANGEABLE CATIONS AT SITE 3



or Ah horizons (S. Pawluk, personal communication).

The increased proportion of sodium and potassium in the Ae horizons of the upper solum in all pedons despite the high mobility and ease of displacement of these cations was attributed by Pawluk (1960) to the probable partial dissolution of Na- and K-bearing minerals under processes of weathering. The proportion of Na and K remain relatively constant throughout the remainder of the pedon.

3. X-ray Diffraction

X-ray diffractograms were obtained for oriented clays saturated with Mg and K on glass slides. The treatments used were (a) Mg saturated-air dried; (b) Mg saturated-glycolated; (c) K saturated-dried at 105°C; and (d) K saturated and heated to 550°C.

Criteria used to evaluate the X-ray diffractograms for identification of clay minerals are presented in Table 8.

Figures 12 to 15 represent X-ray diffractograms of selected soil clays from Site 1. These traces were taken at a rate meter setting of 100 counts per second, a time constant of 16 and zero suppression.

The X-ray data indicate that the clay minerals present in the pedon are variable with respect to depth in the pedon. The Ae_1 and Ae_2 horizons of the pedon exhibit a most dominant peak at 14.2Å in a magnesium saturated-air dry condition. These peaks fail to expand to 16.4Å upon glycolation as would be anticipated for montmorillonite clays. Upon heating to 105°C in a potassium saturated condition the clays result in a diffractogram with a plateau from 10 to 17Å. The plateau effect is also observed in potassium saturated samples heated to 550°C, especially in the Ae_2 horizon suggesting a "mixed layer"

TABLE 8. CRITERIA FOR X-RAY IDENTIFICATION OF CLAY MINERALS

Diffraction[1] Spacing (Å)	Minerals Indicated Under Different Treatments
	Mg Saturated - Air Dry
14 - 15	Montmorillonite, vermiculite, chlorite, interstratified
10.0	Illite (mica)
7.1	Kaolinite, chlorite (2nd order maximum)
	Mg Saturated - Glycolated
14 - 28	Interstratified
16 - 17	Montmorillonite
14	Chlorite, vermiculite
10.0	Illite (mica)
7.1	Kaolinite, chlorite (2nd order maximum)
	K Saturated - 105°C
14 - 15	Chlorite
10 - 14	Interstratified, montmorillonite, vermiculite
10.0	Illite (mica)
7.1	Kaolinite, chlorite (2nd order maximum)
	K Saturated - 550°C
14	Chlorite
10.0	Illite (mica), montmorillonite, vermiculite
7.1	Chlorite (2nd order maximum)

[1] Diffraction spacings underlined are considered diagnostic

structure (Pawluk, 1960). In addition illite, kaolinite and quartz were present as indicated by the 10Å, 7.1Å and 3.34Å peaks respectively.

The Bt and BC horizons showed an increase in peak intensity in all four treatments which suggests the dominant clay mineral to be montmorillonite although "mixed layering" is suggested by magnesium saturated-glycolated and potassium saturated samples heated to 550°C. Also present are significant amounts of quartz, illite and kaolinite.

Figures 16 to 19 represent X-ray diffractograms of soil clays sampled at Site 2. Due to high peak intensities at 100-16-0 it was necessary to obtain the diffractograms at a rate meter setting of 400 counts per second, a time constant of 4 and zero suppression.

The X-ray data indicate relatively little change in mineralogy throughout the pedon. Montmorillonite as denoted by the 14.2Å peak in the magnesium saturated-air dry state, expanded to 16.7Å upon glycolation and contracted to 10Å upon heating potassium saturated samples to 550°C. Also present in these soil clays were quartz, illite and kaolinite. Below the Ae_1 horizon of the pedon peak intensities appear relatively uniform indicating general mineralogical uniformity throughout, with exception of the heavily weathered Ae_1 horizon.

Figures 20 to 23 represent X-ray diffractograms of soil clays selected from Site 3. These diffractograms were obtained at the same instrument setting as was used in samples from Site 2. The clay mineralogy of this pedon is very similar to that obtained from the Site 2 samples. The difference lies in an increased 14Å peak for montmorillonite in the Ae horizon as well as an intensified illite 10Å

peak. The X-ray diffractograms of the Ah horizon in pedons at Site 3 reveal depressed broadened peaks if compared to diffractograms of clays from other horizons from the same pedon. Lesser peak height may be attributed to poorer crystallinity in clays in the surface horizon. The broad peak at 14Å for the Ah horizon clays, failed to expand upon glycolation and remained a plateau above 10Å upon potassium saturation and heating to 550°C suggesting pedogenic interlayers (D. Helgeland, personal communication).

The presence of kaolinite in the X-ray diffractograms was difficult to assess due to the coincidence of a possible second order peak for chlorite and a first order peak for kaolinite. The complete collapse on heating to 550°C and infrared analysis done by G. Coen (personal communication) confirmed its presence in the soils under study.

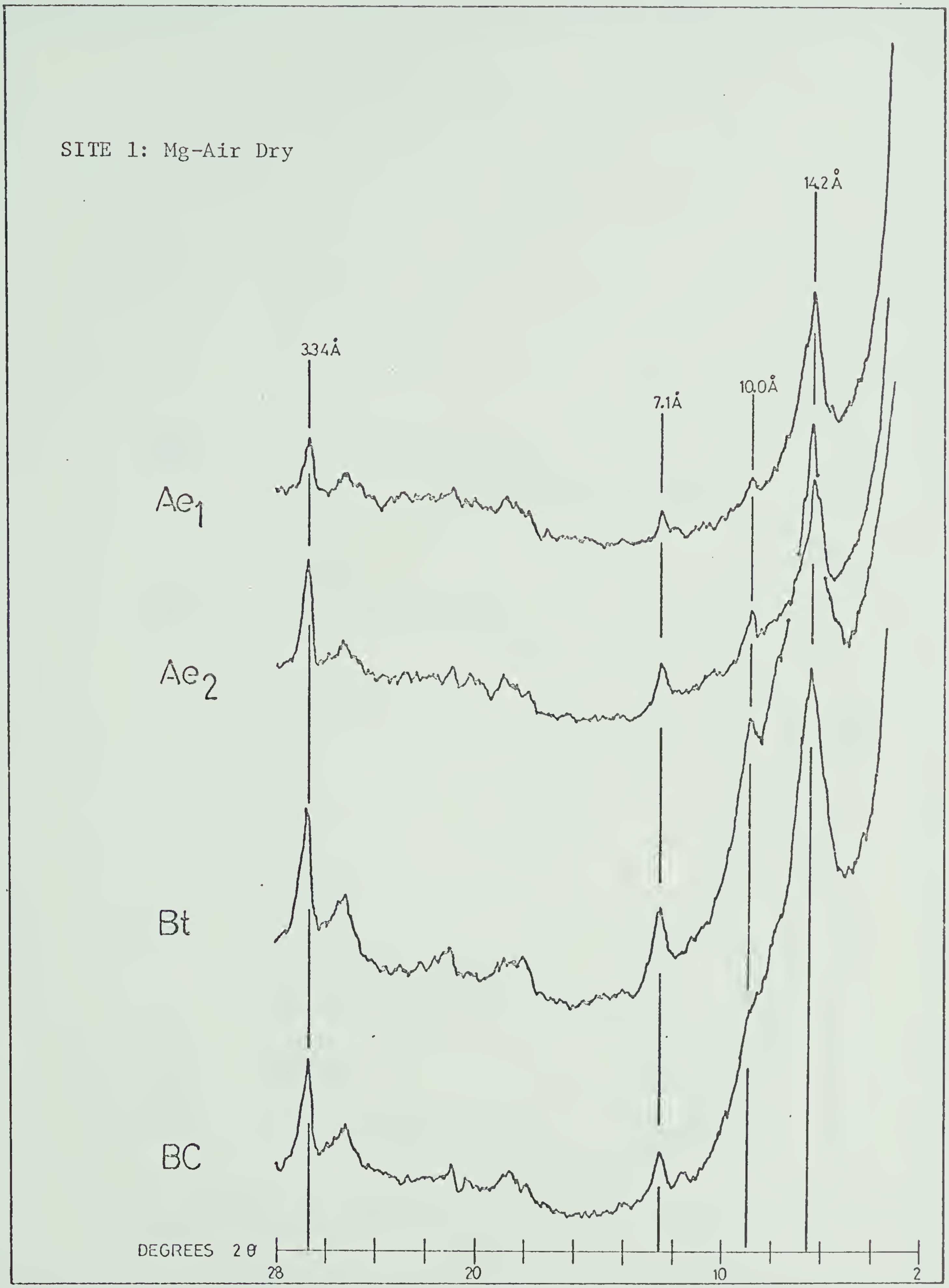


FIGURE 12. X-ray diffractograms of <2μ clays from pedons at Site 1 under Mg saturated - air dry treatments.

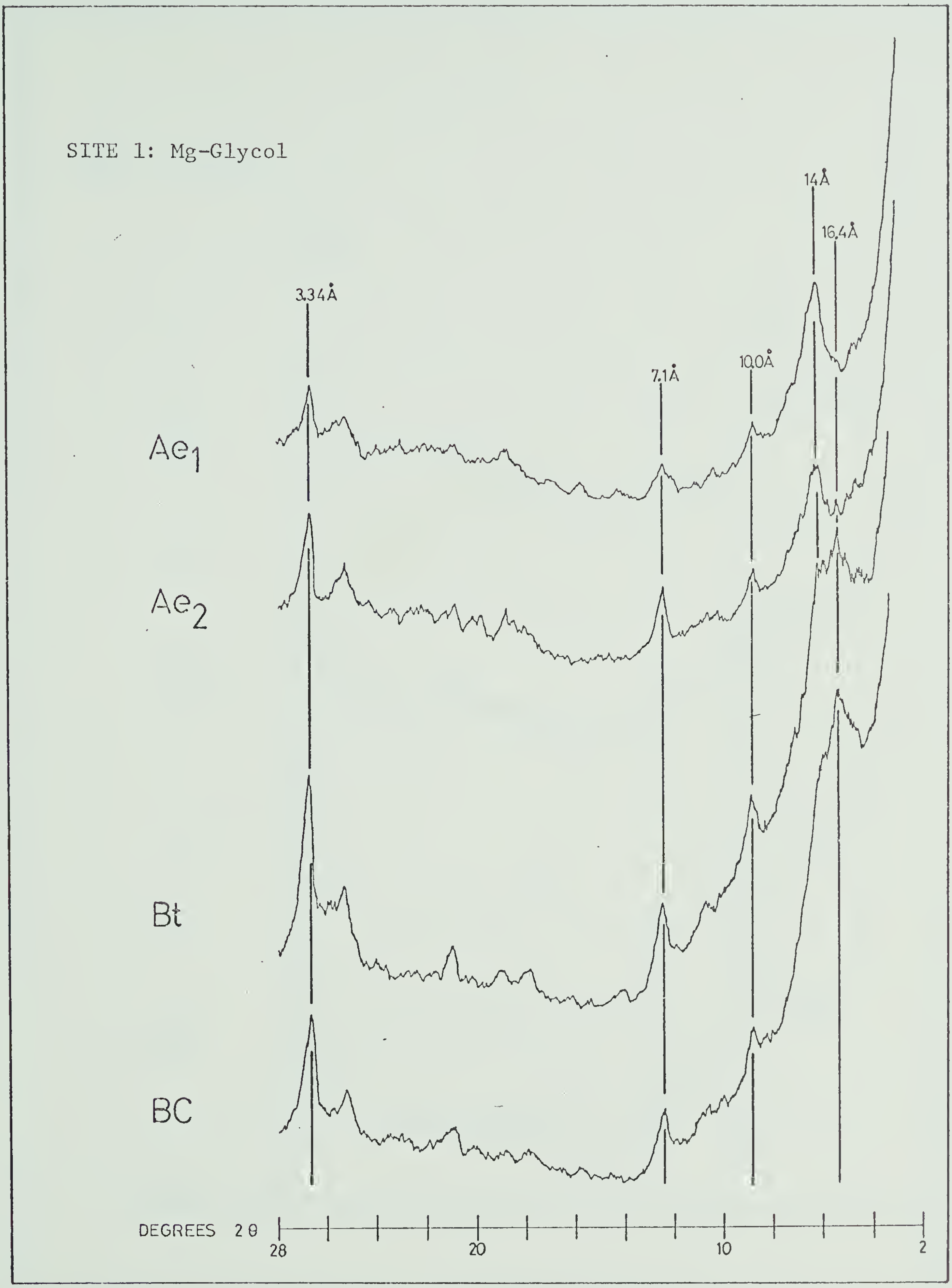


FIGURE 13. X-ray diffractograms of <2μ clays from pedons at Site 1 under Mg saturated - glycolated treatments.

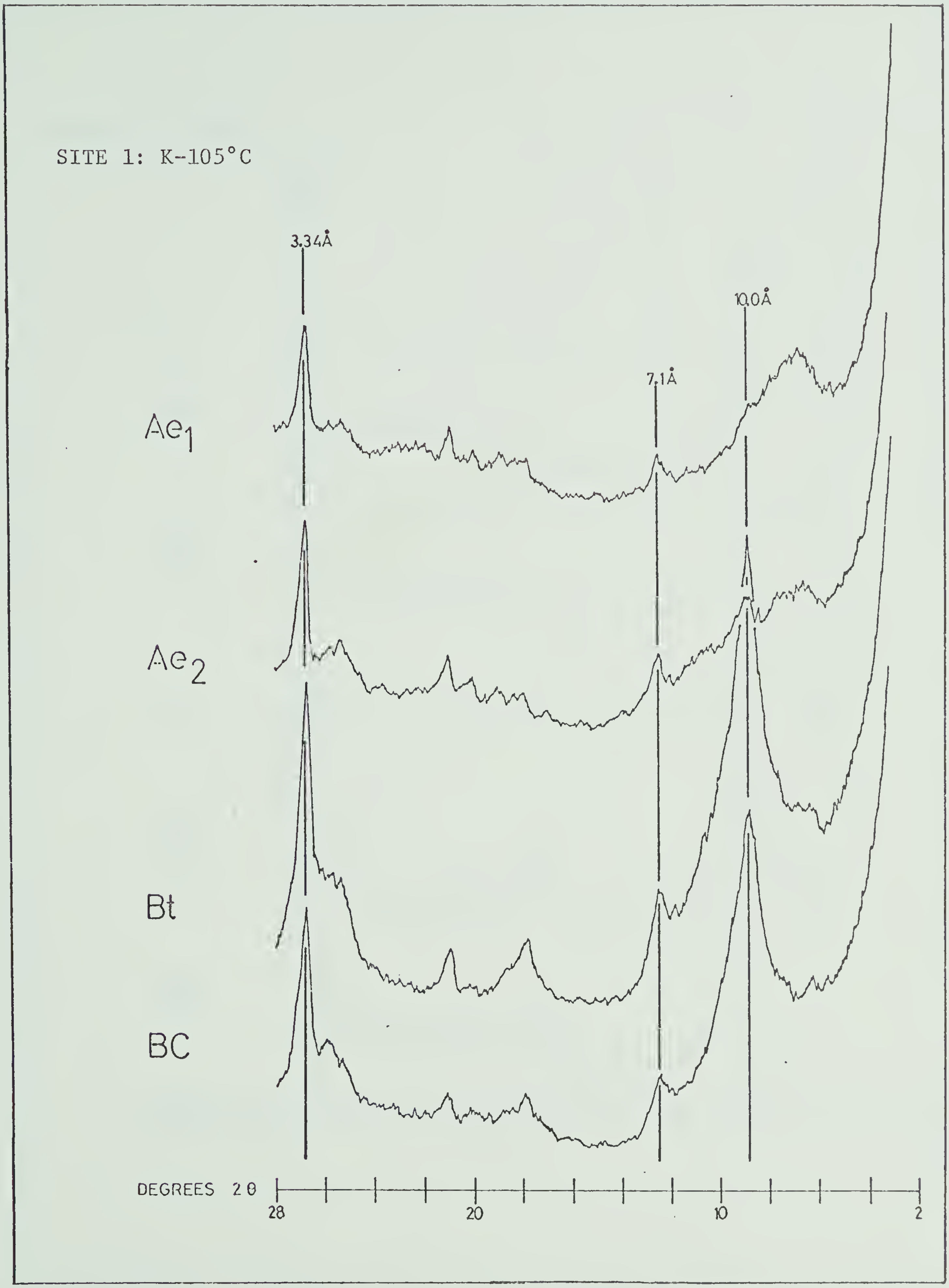


FIGURE 14. X-ray diffractograms of <2μ clays from pedons at Site 1 under K saturated treatments dried at 105°C.

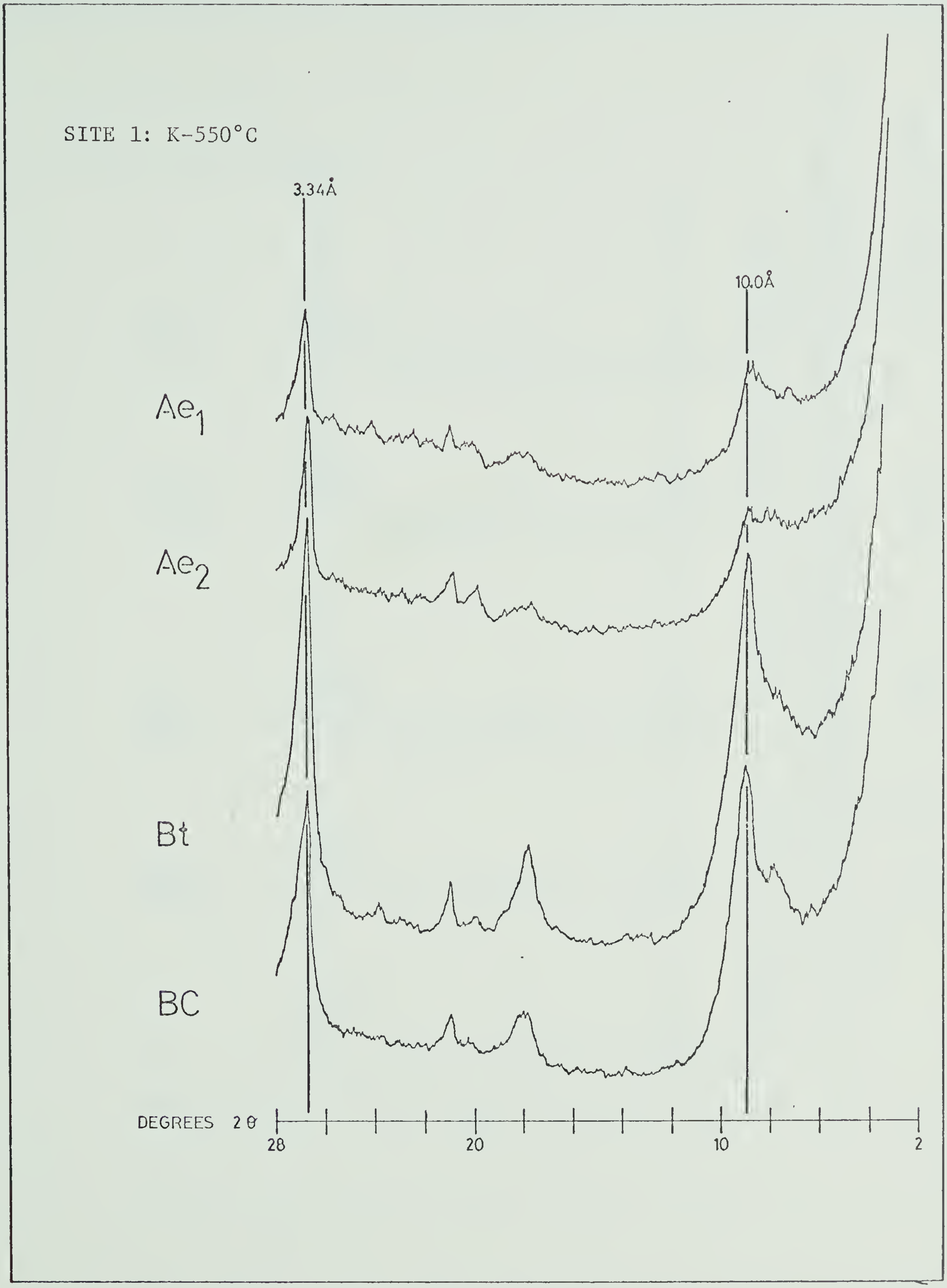


FIGURE 15. X-ray diffractograms of <2μ clays from pedons at Site 1 under K saturated treatments heated to 550°C.

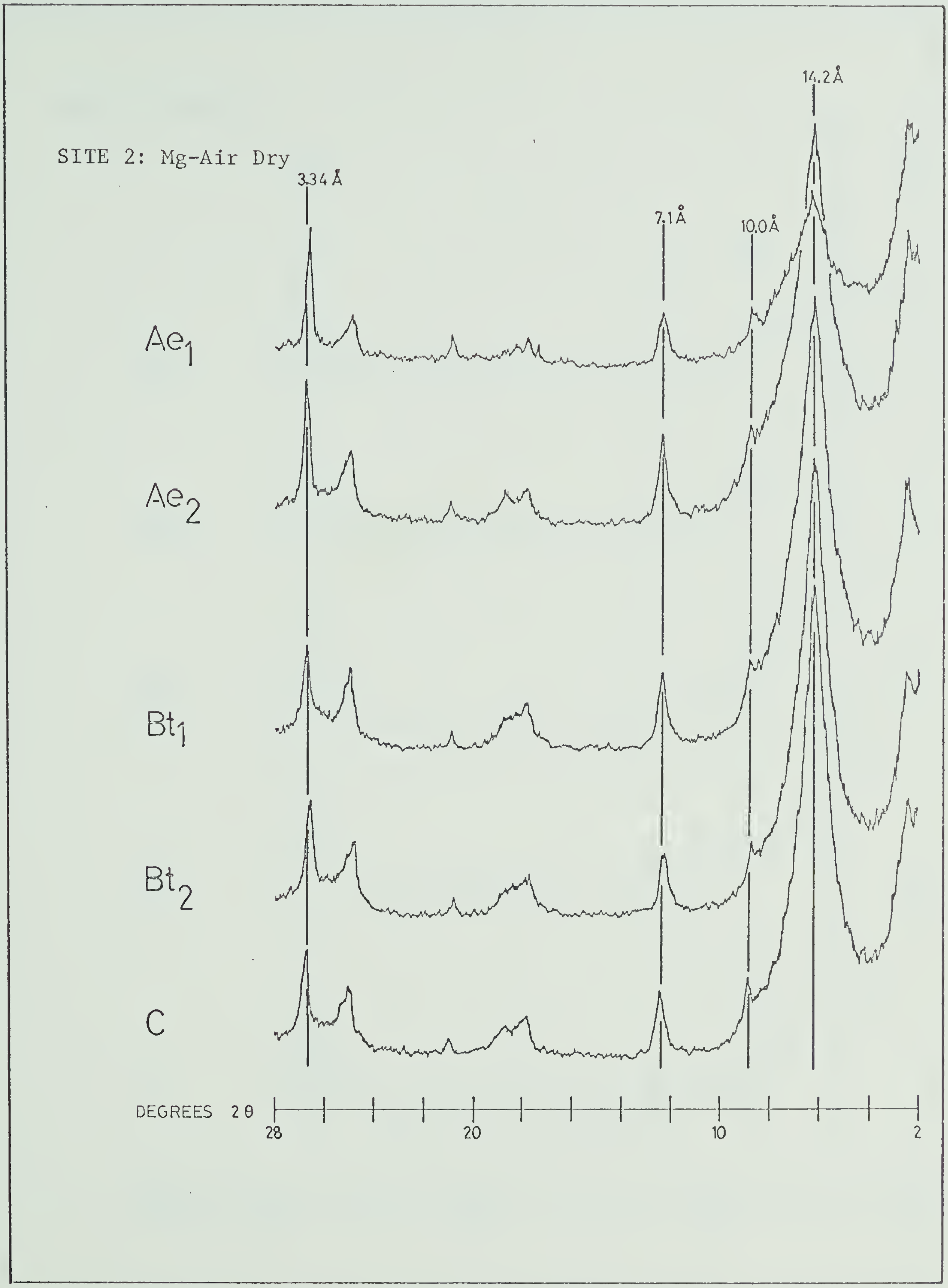


FIGURE 16. X-ray diffractograms of <2μ clays from pedons at Site 2 under Mg saturated - air dry treatments.

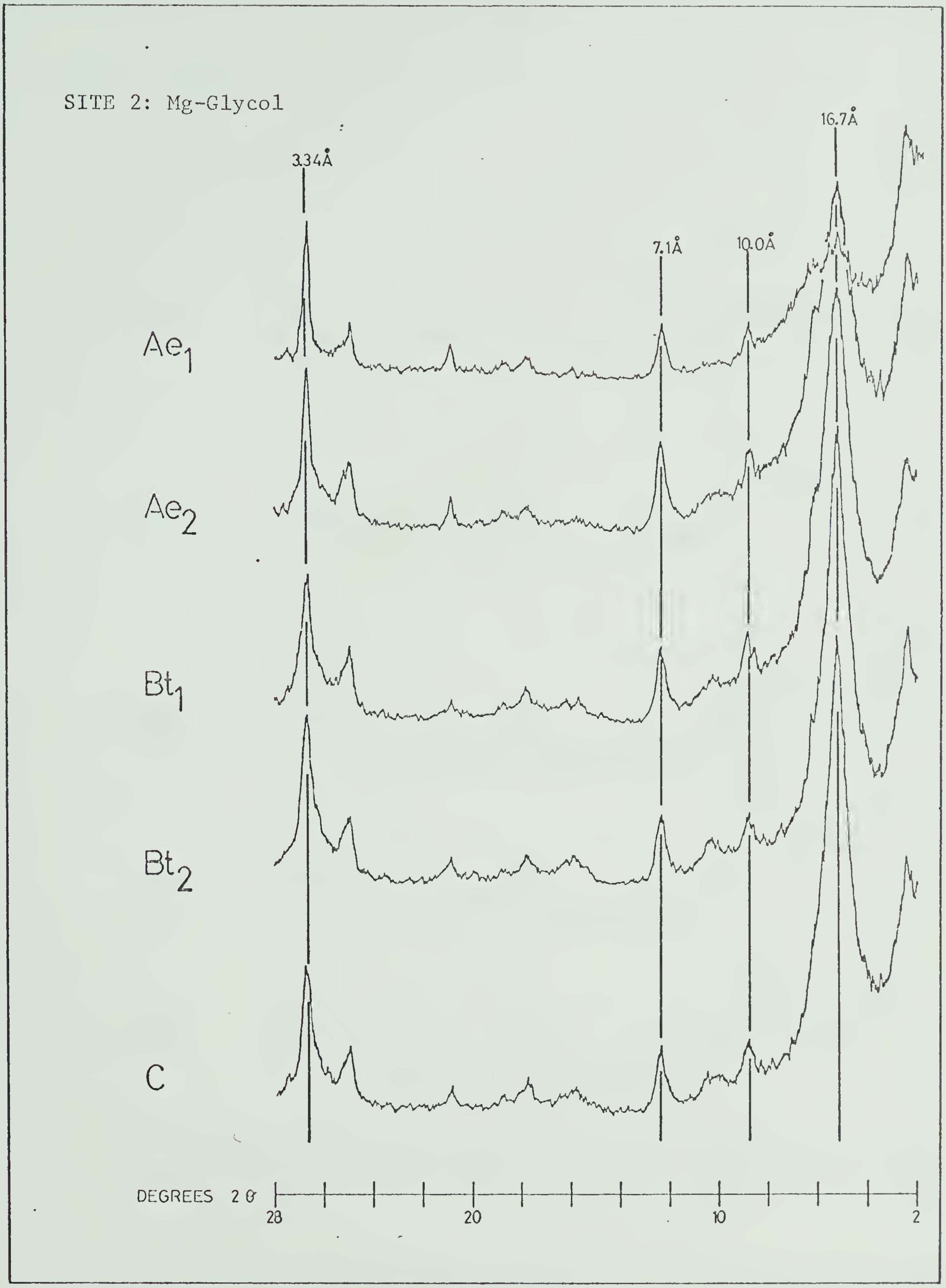


FIGURE 17. X-ray diffractograms of <2μ clays from pedons at Site 2 under Mg saturated - glycolated treatments.

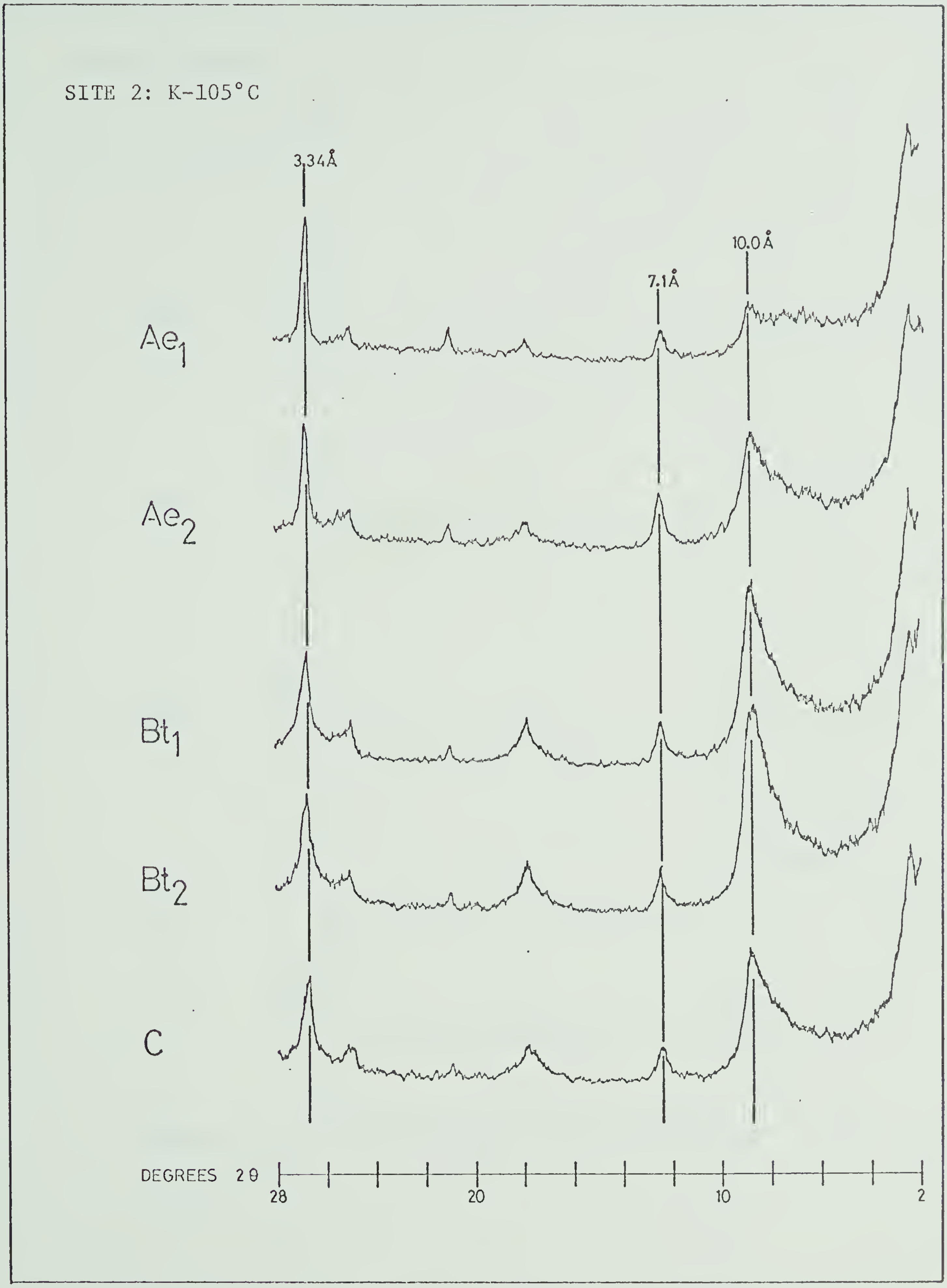


FIGURE 18. X-ray diffractograms of <2μ clays from pedons at Site 2 under K saturated treatments dried at 105°C.

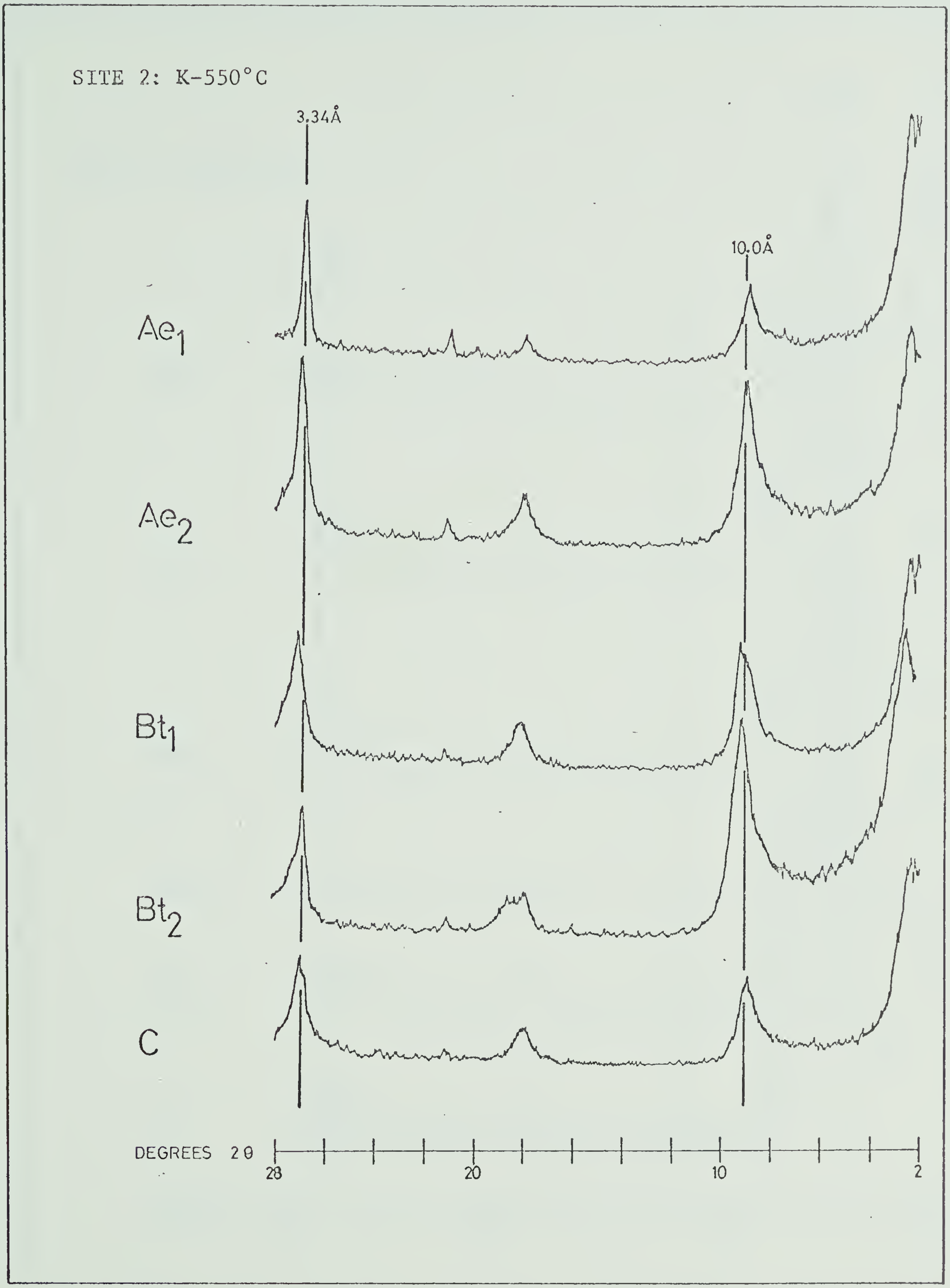


FIGURE 19. X-ray diffractograms of <2μ clays from pedons at Site 2 under K saturated treatments heated to 550°C.

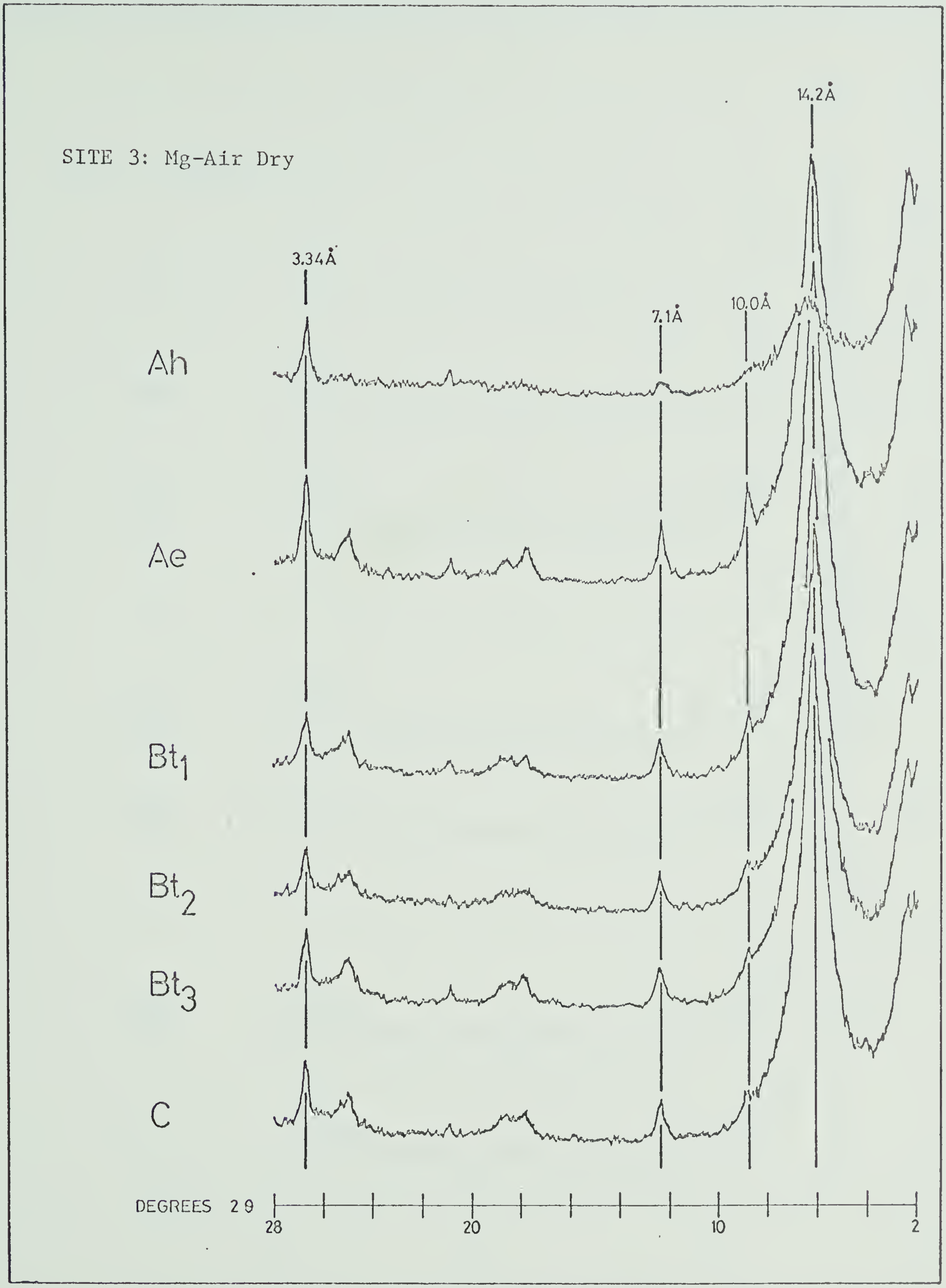


FIGURE 20. X-ray diffractograms of <2μ clays from pedons at Site 3 under Mg saturated - air dry treatments.

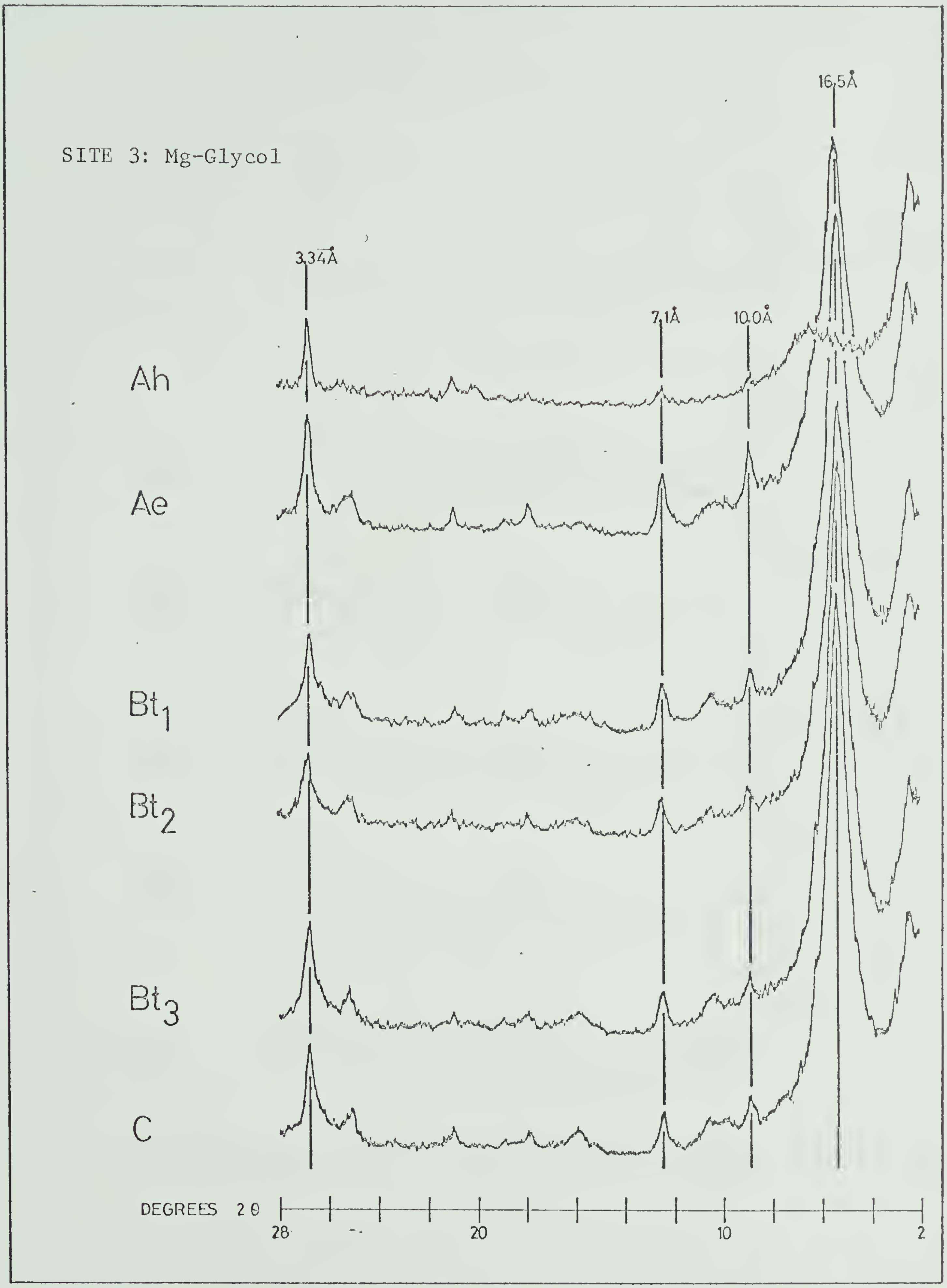


FIGURE 21. X-ray diffractograms of <2μ clays from pedons at Site 3 under Mg saturated - glycolated treatments.

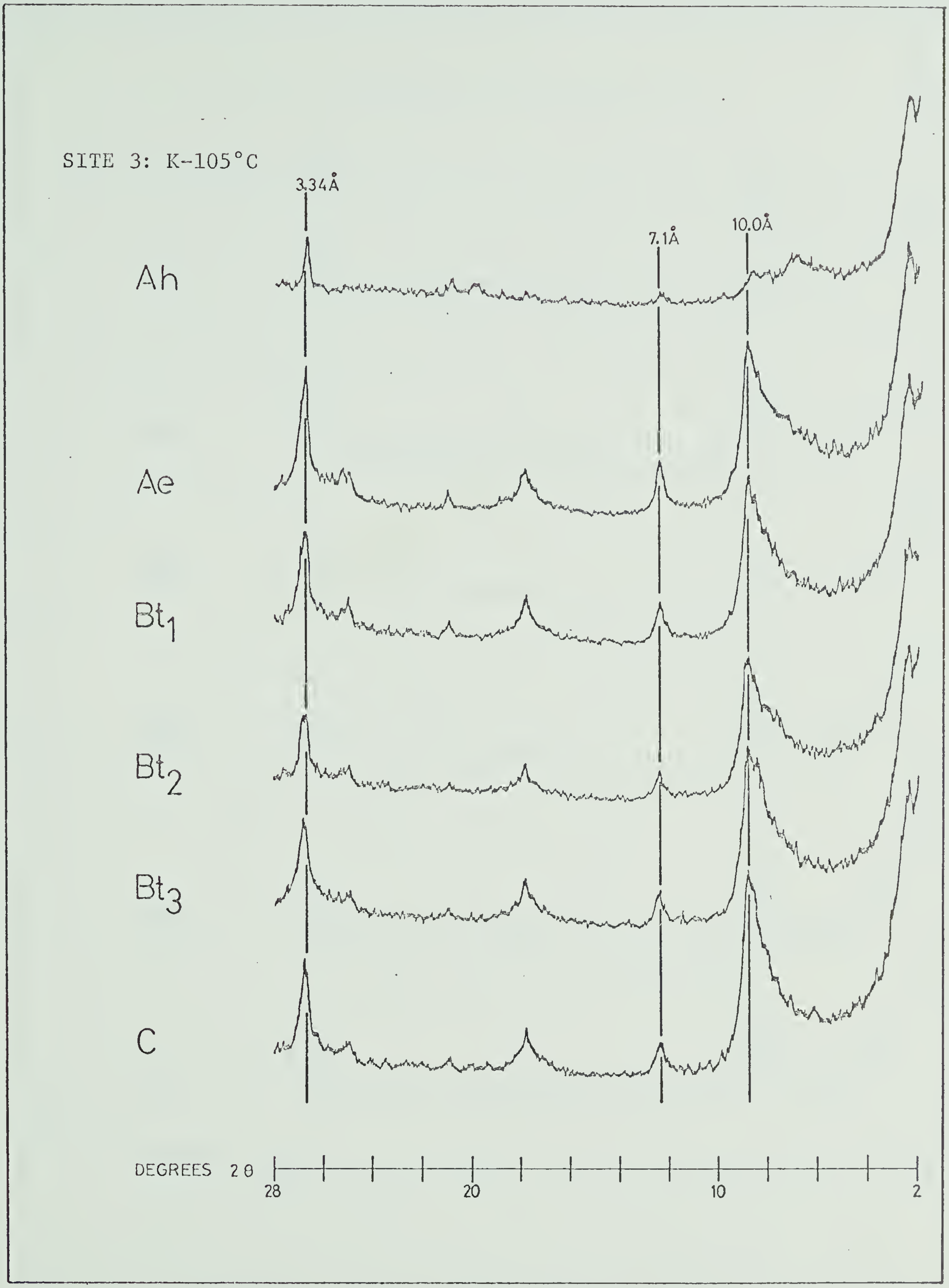


FIGURE 22. X-ray diffractograms of <2μ clays from pedons at Site 3 under K saturated treatments dried at 105°C.

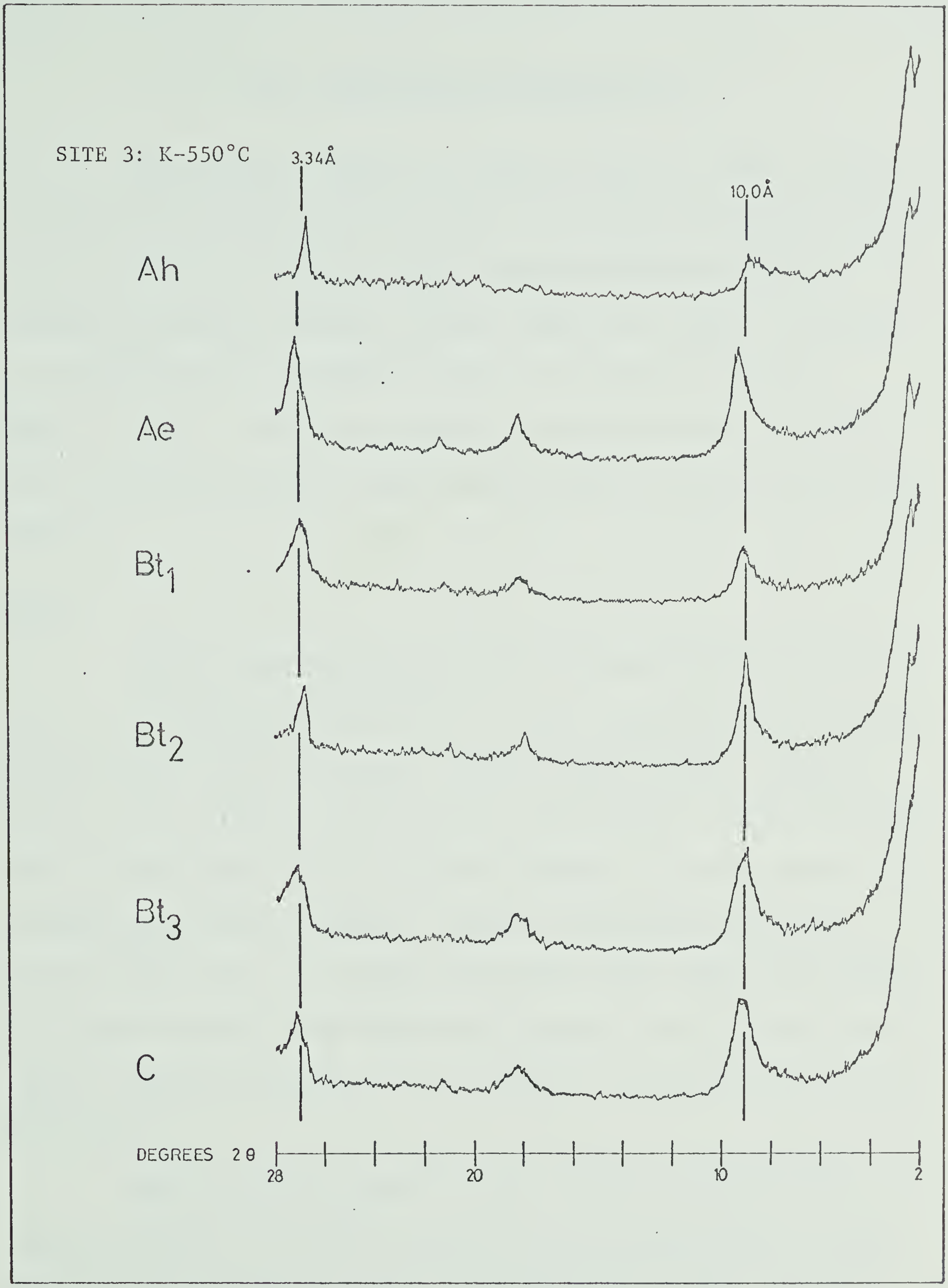


FIGURE 23. X-ray diffractograms of <2μ clays from pedons at Site 3 under K saturated treatments heated to 550°C.

II. DESCRIPTIVE MICROMORPHOLOGY

Thin sections, prepared in duplicate from the upper and lower portion of each Bt horizon in each pedon were examined microscopically using the criteria of Parfenova and Yarilova (1962) and described employing terminology defined by Brewer (1964a, and 1964b). A portion of the terminology is presented in Table 9 and defined according to Brewer's concepts. Horizons in pedons are described below with reference to observed features, trends and differences in the upper and lower segments.

Site 1

Plasma in duplicate thin sections examined from Bt horizons of pedons of the Coalspur Series at Site 1, was a relatively uniform light grayish brown color in the upper, central (where sampled), and lower portions of the horizon. Darker brown areas caused by clays with associated iron and organic staining occurred randomly in some instances, and in some fairly complex networks. Randomly distributed mottles were evident within peds in all samples taken from these pedons. The plasma in the upper portion of the horizon was generally closely packed around skeletal members and packing density appeared to increase with depth in the horizon.

Small, poorly to moderately well defined, rounded blocky (equant polyspheric), partially accommodated to unaccommodated primary peds were the predominant form of aggregation in the upper portion of the horizon. The majority of these primary peds coalesced to larger, less well defined, rounded blocky, partially accommodated secondary peds

TABLE 9. DEFINITIONS OF SELECTED MICROMORPHOLOGICAL TERMS AS ELUCIDATED BY BREWER (1964a, and 1964b)

s-matrix:

material within the simplest peds, or composing apedal soil materials, in which the pedological features occur; it consists of the plasma, skeleton grains, and voids that do not occur in pedological features other than plasma separations.

Peds:

(1) Primary peds: an integration of a characteristic size, shape, and arrangement of basic structure. The simplest peds occurring in a soil material; they cannot be divided into smaller peds, but they may be packed together to form compound peds of a higher level of organization.

(2) Secondary peds: The size, shape, and arrangement of the primary peds, their interpedal voids, and associated interpedal pedological features in a soil material.

(3) Tertiary peds: The size, shape, and arrangement of the secondary peds of a soil material, their interpedal voids and associated interpedal pedological features.

Packing of Peds:

(1) Regular: packing in which there is some orderly arrangement with regard to shape.

(2) Random: there is no apparent orderly arrangement, usually because of the highly irregular shape of peds.

Accommodation of Peds:

(1) Accommodated: All the faces are accommodated by the faces of

TABLE 9 (continued)

adjoining peds.

(2) Partially accommodated: Some of the faces are accommodated by the faces of adjoining peds.

(3) Unaccommodated: Virtually none of the faces are accommodated by the faces of adjoining peds; adjoining peds touch only at points.

Shape of Peds:

(1) Subrounded blocky: Equivalent to equant polyhedric, i.e. ($b/a > 2/3$, $c/b > 2/3$). The ped has mixed curved and plane faces; re-entrant angles are absent or weakly developed.

(2) Rounded blocky: Equivalent to equant polyspheric. The specifications and qualifications are as for subrounded blocky except that all faces are curved; re-entrant angles are absent or weakly developed.

Voids:

(1) Interpedal: Voids occurring between peds.

(2) Intrapedal: Voids occurring within the s-matrix of peds or apedal soil materials.

(3) Compound packing voids: These voids result from packing of compound individuals, such as peds, which do not accommodate each other. They are unoriented, have a random distribution, and are usually equant to prolate, irregular orthovoids, or smoothed metavoids; they are strongly interconnected.

(4) Vughs: Vughs are relatively large voids, other than packing voids usually irregular and not normally interconnected with other voids of comparable size. They may be orthovughs (irregular) or smoothed metavughs, are usually unoriented

TABLE 9 (continued)

and have a random distribution pattern.

(5) Planes: They are voids that are planar by the ratios of their principal axis.

(a) Joint planes: Planar voids that traverse the soil material in some fairly regular pattern, such as parallel or sub-parallel sets. Their surfaces are usually smoothed, quite commonly slickensided.

(b) Skew planes: Planar voids that traverse the soil material in an irregular manner, having no specific basic distribution or orientation pattern between individuals.

(c) Craze planes: These are planar voids with a highly complex conformation of the walls due to interconnection of numerous short flat and/or curved planes.

Skeleton:

Random: The plasma occurs as a dense groundmass in which skeleton grains are set after the manner of phenocrysts in a porphyritic rock.

Cutans:

A modification of the texture, structure or fabric at natural surfaces in soil materials due to concentration of particular soil constituents or *in situ* modification of the plasma; cutans can be composed of any of the component substances of the soil material.

(1) Free grain cutans: occur on the surfaces of grains which form the walls of voids.

(2) Embedded grain cutans: occur on the surfaces of grains embedded

TABLE 9 (continued)

in a relatively densely packed plasma.

(3) Plane cutans: Cutans associated with the walls of planar voids. As used in this study plane cutans will also include those on planes between peds. They are divided into joint-plane cutans, skew plane cutans and craze plane cutans.

(4) Argillans: Argillans are those cutans composed dominantly of clay minerals. Commonly the clay minerals are mixed with some contaminant.

Characteristics of Cutans:

(1) Sharpness of boundary: refers to the boundary between cutanic material and the normal soil material since the other boundary is sharp because it is within a void or a solid entity, such as a skeleton grain or a nodule. It is recorded as very diffuse, diffuse, rather diffuse, rather sharp or sharp.

(2) Degree of Separation: deals with the degree of contrast in fabric or concentration of material between cutanic and non-cutanic soil material. It is recorded as slightly separated, weakly separated, moderately separated or strongly separated.

Plasma Separations:

Features characterized by a significant change in the arrangement of the constituents rather than a change in concentration of some fraction of the plasma. An example is the change in orientation of the clay mineral fraction near the surface of slickensides.

Orientation Patterns:

(1) Continuous orientation: Under crossed nicols the mass of

TABLE 9 (continued)

plasma exhibits extinction lines or extinguishes as a unit.

(2) Striated orientation: The plasma aggregates are physically and/or optically anisotropic and exhibit a linear or curved linear arrangement.

(3) Flecked orientation: The plasma aggregates are arranged randomly.

Glaebules:

A three-dimensional unit within the s-matrix of the soil material, and usually prolate to equant in shape; its morphology (especially size, shape, and/or internal fabric) is incompatible with its present occurrence being within a single void in the present soil material. It is recognized as a unit either because of a greater concentration of some constituent and/or a difference in fabric compared with the enclosing soil material.

Plasmic Fabrics:

Sepic Plasmic Fabrics: These fabrics have recognizable anisotropic domains with various patterns of preferred orientation; that is, plasma separations with a striated extinction pattern are present.

(1) Vosepic plasmic fabric: Part of the plasma has a flecked orientation pattern, but plasma separations with striated orientation occur associated with the walls of voids.

(2) Skelsepic plasmic fabric: Part of the plasma has a flecked orientation pattern, but plasma separations with striated orientation occur at the surfaces of skeleton grains.

(3) Masepic plasmic fabric: Part of the plasma has a flecked

TABLE 9 (continued)

orientation pattern, but plasma separations occur as zones within the s-matrix apparently not associated with the walls of voids or the surfaces of skeleton grains.

which were in the majority of cases randomly packed (Plate 1.1). Aggregation in the lower portion consisted of moderately well defined rounded blocky, partially accommodated primary peds. Compared with the upper portion, the peds, with the exception of pedon 5, appeared larger and aggregation better expressed. As stated for the upper portion the majority of these structural features coalesced to larger rounded blocky partially accommodated secondary peds, which were randomly packed for the majority of cases. Thin sections from pedon 3 in all cases revealed the poorest visible structural definition. Extremes in micromorphological structures were greater in this horizon than in any Bt horizon from pedons of the other two sites.

The most pronounced or most readily expressed type of pore space in the upper portion of the Bt horizon was interpedal voids best classified as skew planes and craze planes due to the relative abundance of short interconnected planes in an irregular network, commonly resulting in a complex formation (Plate 1.1). In some cases these interpedal voids could have been classified as compound packing voids since by visual observation, many appear to result from packing of compound individuals. Peds which in many cases do not accommodate one another are generally accepted as an indication of such packing (Brewer, 1964a). Material heterogeneity with respect to particle size and packing arrangement as well as irregular drying are proposed as possible causes of this arrangement of irregular planes by Brewer (1964a). This proposition and the criteria which were used to verify it are very similar to Sleeman's (1963) concepts of ped formation with the occurrence of cracks lessening as depth in pedon increases. The explanation used by these two authors

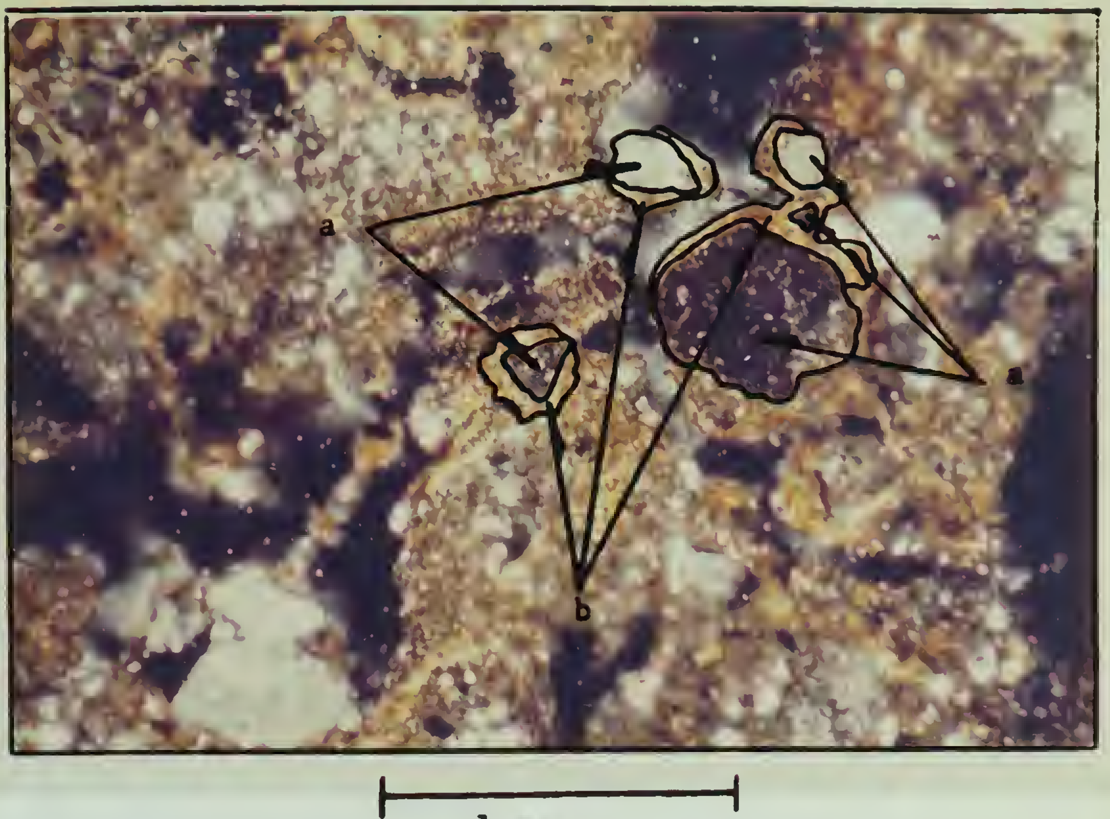


Plate 1.1 Photomicrograph of skelsepic plasmic fabric from upper portion of Bt horizon showing strongly expressed skeletal cutans (crossed polarizers). (Site 1, Pedon 5, Upper portion Bt)

a. Skeleton
b. Cutans

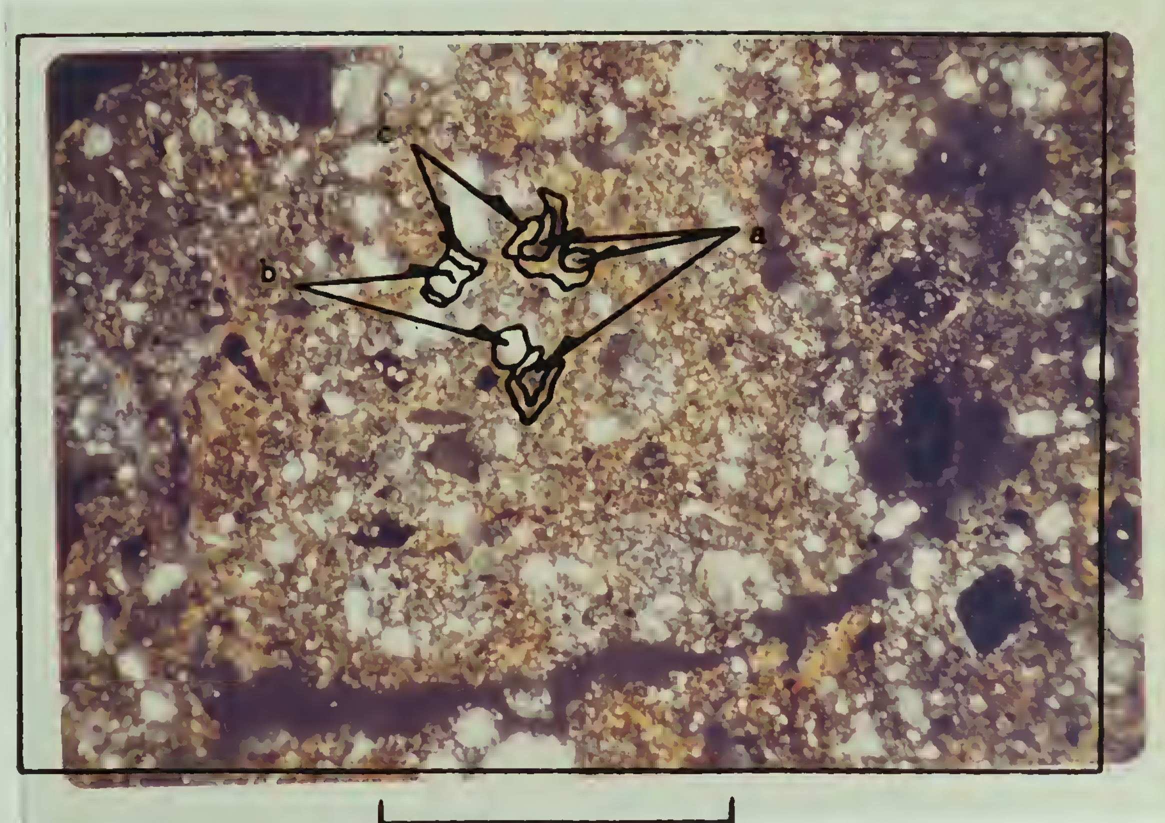
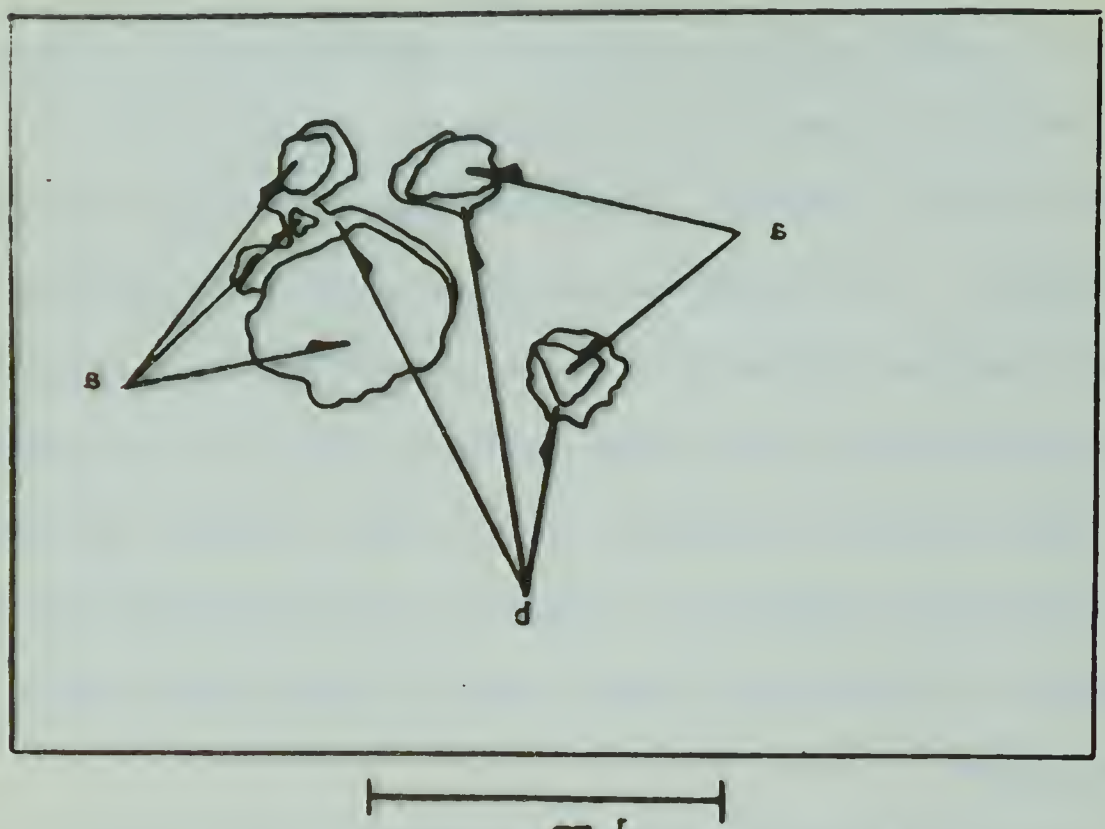
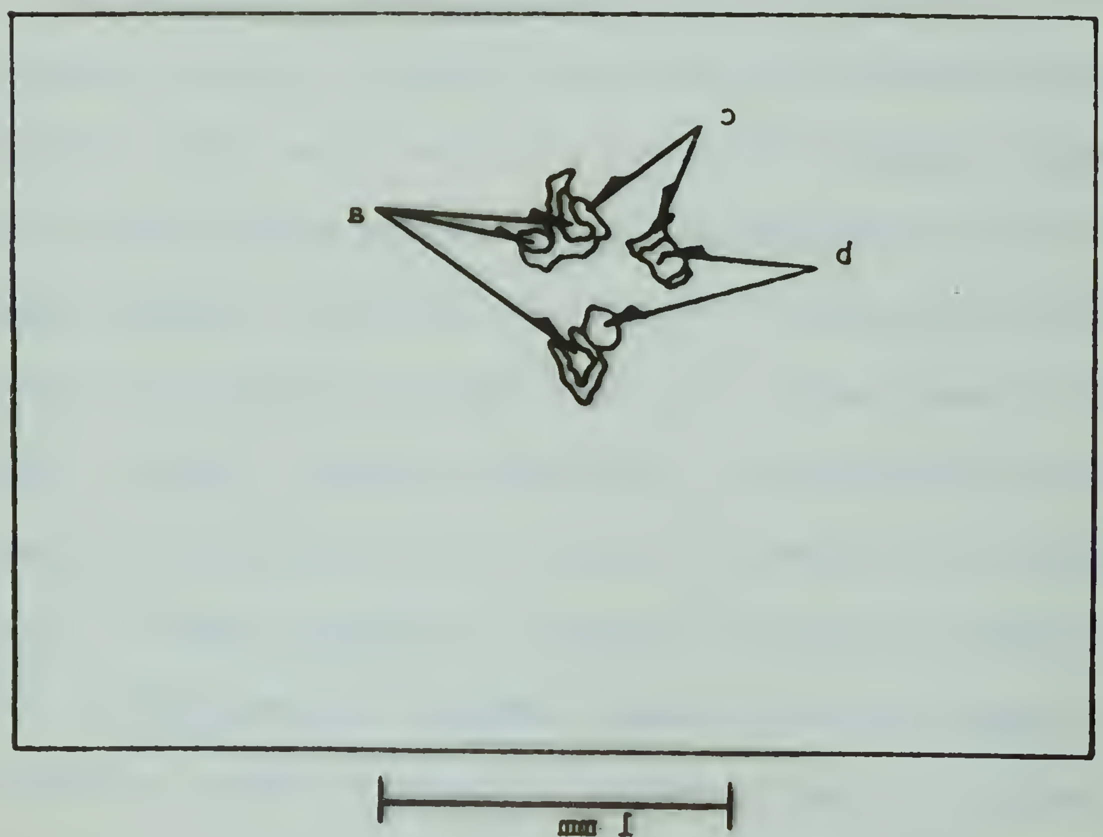


Plate 1.2 Photomicrograph of vo-skelsepic plasmic fabric showing skeleton and vugh argillans (crossed polarizers). (Site 1, Pedon 2, Upper portion Bt).

a. Vughs
b. Skeleton
c. Cutans



a. Skeleton
b. Cutans



a. Vughs
b. Skeleton
c. Cutans

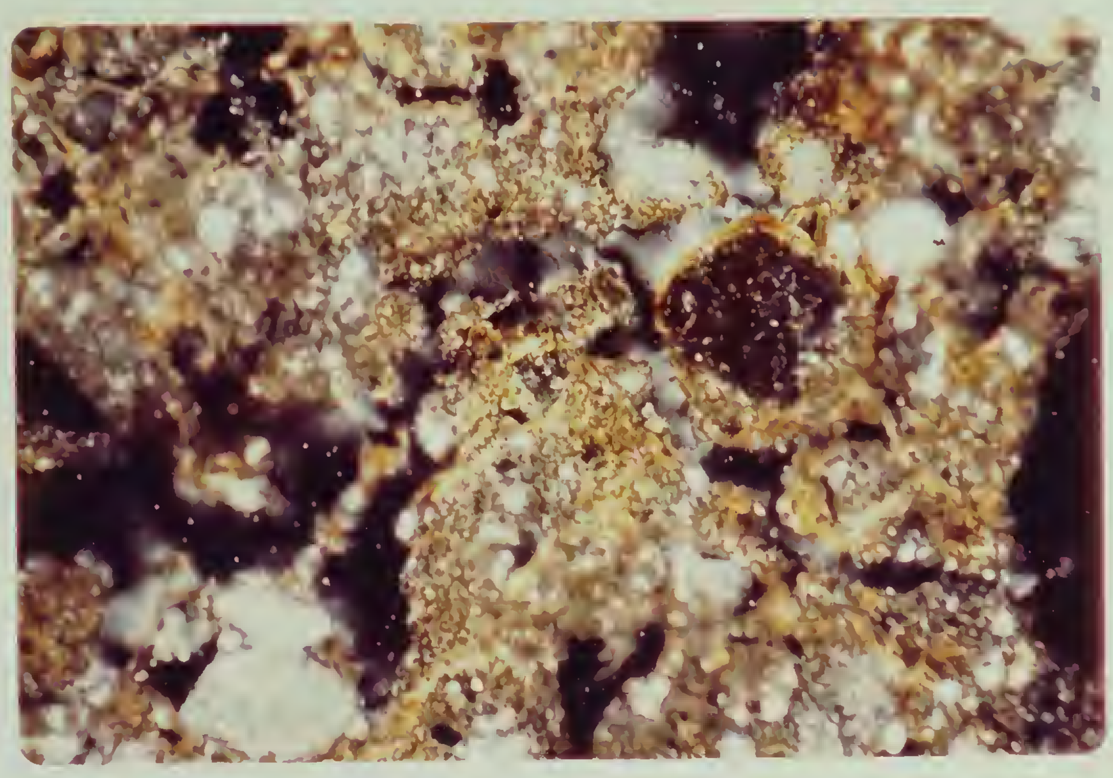


Plate 1.1 Photomicrograph of skelsepic plasmic fabric from upper portion of Bt horizon showing strongly expressed skeletal cutans (crossed polarizers). (Site 1, Pedon 5, Upper portion Bt)

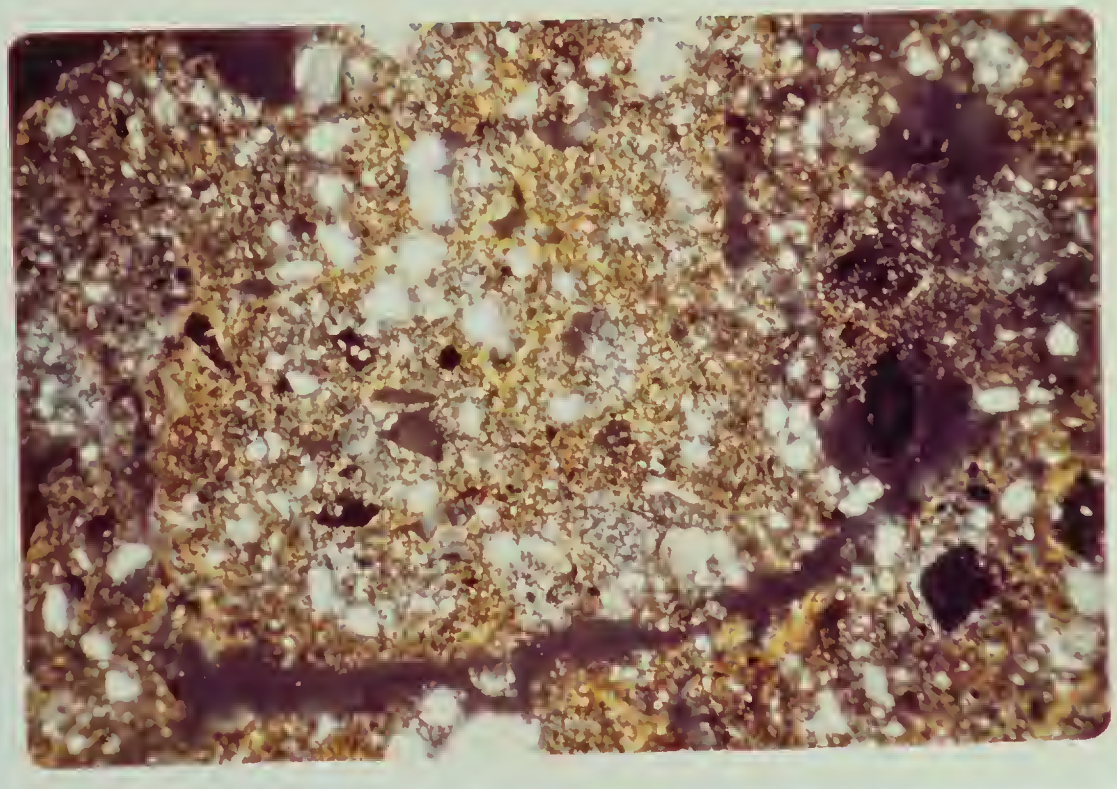


Plate 1.2 Photomicrograph of vo-skelsepic plasmic fabric showing skeleton and vugh argillans (crossed polarizers). (Site 1, Pedon 2, Upper portion Bt).

with respect to planar voids was not borne out by petrographic examination of thin sections from the Bt horizons of these pedons. The proportions and arrangement of these "planar" interpedal voids remained unaltered throughout the horizon, as concluded from visual observation.

Relatively large intrapedal voids, classified as ortho-and metavughs, occurred randomly in both portions of the horizon. Most of the vughs were meta in character as indicated by microscopic observation at both levels. The areal proportion of vughs appeared to decrease with increasing depth. The dimensions of vughs, obtained by measurement of the shortest dimension, were variable in the upper level between 15 and 1600μ. Vughs in the lower portion of the horizon varied from 25 to 1100μ.

The organic matter content of the Bt horizon was low and randomly distributed. The degree of decomposition of the organic fragments varied from the most predominant intact tissues of root sections to occasional irregularly shaped darkened fragments. In the instances of partially decomposed organic matter, the adjoining plasma was generally a darker colored material due to the association with decomposing organic material. In addition organic stained areas were generally observed to be associated with areas of iron staining. The arrangement of the organic fragments was highly variable in the Bt horizons of Site 1, being associated with interpedal voids, large intrapedal vughs and in some cases were located within peds with the root fragment closely surrounded by plasmic material.

The dominant mineral component of the skeletal fraction was quartz with occasional feldspar. The size distribution of mineral

grains, as controlled by the magnification used, varied from about 15 to 500μ in both the upper and lower portions of the horizon. Chert and fragments of sandstone, siltstone and shale, variable from 0.2 mm to greater than 3.5 mm, made up the majority of the remaining skeletal fraction. Most of the sedimentary rock fragments were rounded and a large number revealed fractures which appeared due to *in situ* weathering. The distribution pattern of skeletal members within the plasma was best defined as random.

The plasma in the upper and lower portion of the Bt horizon was in general closely packed, moderately uniform throughout and occasionally interspersed with root fragments. Argillans in the upper portion of the horizon were variable from less than 8 to 30μ in thickness. The dominant cutanic feature by visual observation of the thin sections from the upper portion of the horizon was embedded grain argillans which had a strong and relatively continuous, parallel orientation to the skeleton grains (Plates 1.1 and 1.2). These argillans had a sharp boundary and were strongly separated at the magnification used in micromorphological observations (30 x). Skew and craze plane argillans with moderately strong, discontinuous, parallel orientation were noted occasionally. These argillans although very limited in length and thickness did appear to have sharp boundaries and were strongly separated. In addition vugh argillans with strong, discontinuous, parallel orientation, sharp boundaries and strong separation were observed (Plate 1.2). The variability of cutanic features among pedons at Site 1 was extensive. The Bt horizon of pedon 3 had embedded grain argillans, but very few plane and vugh argillans existed. Pedon 4 represented the other extreme of the range

with the most continuous plane and vugh argillans observed at this site.

Argillans in the lower portion of the horizon ranged from less than 8μ to 85μ in thickness. The cutanic features consisted primarily of embedded grain argillans with strong, relatively continuous, parallel orientation, strongly separated with sharp boundaries. Skew and craze plane argillans with strong, discontinuous, parallel orientation, sharp boundaries and strong separation were present in the upper portion of the horizon. The dimensions of these argillans both in length and thickness exceeded those for the upper portion of the horizon in each pedon. This increased degree of development of skew and craze plane argillans in the lower portion of the horizon also characterized differences for vugh argillans.

Occasional plasma separations within the aggregates were observed in the lower portion of the horizon. These consisted of short, thin striated zones of clays with parallel orientation. The arrangement of these plasma separations was random, in that in no case did they appear to be related to any other observed feature.

Glaebules with undifferentiated internal fabric (nodules) were observed in both parts of the horizon. These nodules were generally of an irregular shape with a diffuse boundary. The origin of this form of glaebules is generally attributed to in situ accretion of soluble constituents which accumulate by diffusion or crystallization from solution in the numerous, very small voids in the s-matrix due to suitable local chemical conditions (Brewer, 1964a). Alternately, it is suggested that glaebules with diffuse boundaries may originate because chemical conditions within the glaebule are not greatly different from the surrounding soil

material for deposition of the accreting constituent.

The plasmic fabric of the Bt horizons from Site 1 varied between the upper and lower portions of the horizon as well as among pedons. The fabric of the upper portion of the horizon was for the most part skel-sepic with a porphyroskelic skeletal arrangement. The lower portion of the horizon possessed a vo-skelsepic plasmic fabric with a random skeleton.

The descriptive micromorphological characterization of the Bt horizons in pedons at Site 1 reveals some interpretive information on processes of pedogenesis. Strongly oriented void argillans are generally indicative of illuviation (Brewer, 1964a), which is supported in this case by their increasing abundance with depth in the horizon. The sharpness of the boundary between these clay mineral cutans and the noncutanic material adds additional support to the suggested process of illuviation. The discontinuous nature of these argillans however is not in agreement with concepts (Brewer, 1964a) regarding formation of cutans by illuviation. Illuviation cutans are in the majority of cases continuous unless other processes are operative. Information concerning structure of aggregates and pore space given in this section and in the section concerning morphological characterization of the Bt horizons of the pedons in addition to cutanic features suggests the possibility of additional processes of pedogenesis (Brewer, 1968). It is proposed that the process of non-destructive mass wasting, as suggested by Pettapiece (1970) in conjunction with illuviation and material heterogeneity are the most probable causes of this plasmic fabric. Additional support for this proposal is rendered by the large proportion of oriented embedded grain argillans which

Brewer (1964a) attributes to rotation of skeletal grains under stress.

Site 2

The plasmic fraction of the s-matrix in the upper and lower portions of the Bt_1 horizon of pedons of the Hubalta Series from Site 2 was a relatively uniform, gray brown color with an abundance of darker areas due to clays and associated iron and/or organic staining (Plate 2.1). Mottles occurred randomly in the s-matrix. The plasmic materials, in both portions of the horizon were densely packed about the skeleton.

Relatively large moderately well to well defined subrounded blocky (equant polysphedric), accommodated primary peds were the dominant form of aggregation in the upper and lower portion. The packing of peds in both segments of the horizon was regular. A small portion of these peds coalesced to less well to poorly defined, subrounded blocky, accommodated secondary peds. Visual observation suggested larger forms of primary peds in the lower areas of the horizon.

The predominant pore space in this horizon was interpedal voids in the manner of skew planes with smoothed walls (cutanic surfaces). These were longer, more linear and less abundant than those observed in pedons at Site 1 and formed an irregular network. In addition lesser amounts of skew and craze planes existed as interpedal voids than in Bt horizons at Site 1. Complex networks of craze planes, characteristic of Bt horizons at Site 1 were nonexistent.

Intrapedal voids consisted almost entirely of metavughs (Plate 2.2) which occurred randomly within the s-matrix of both the

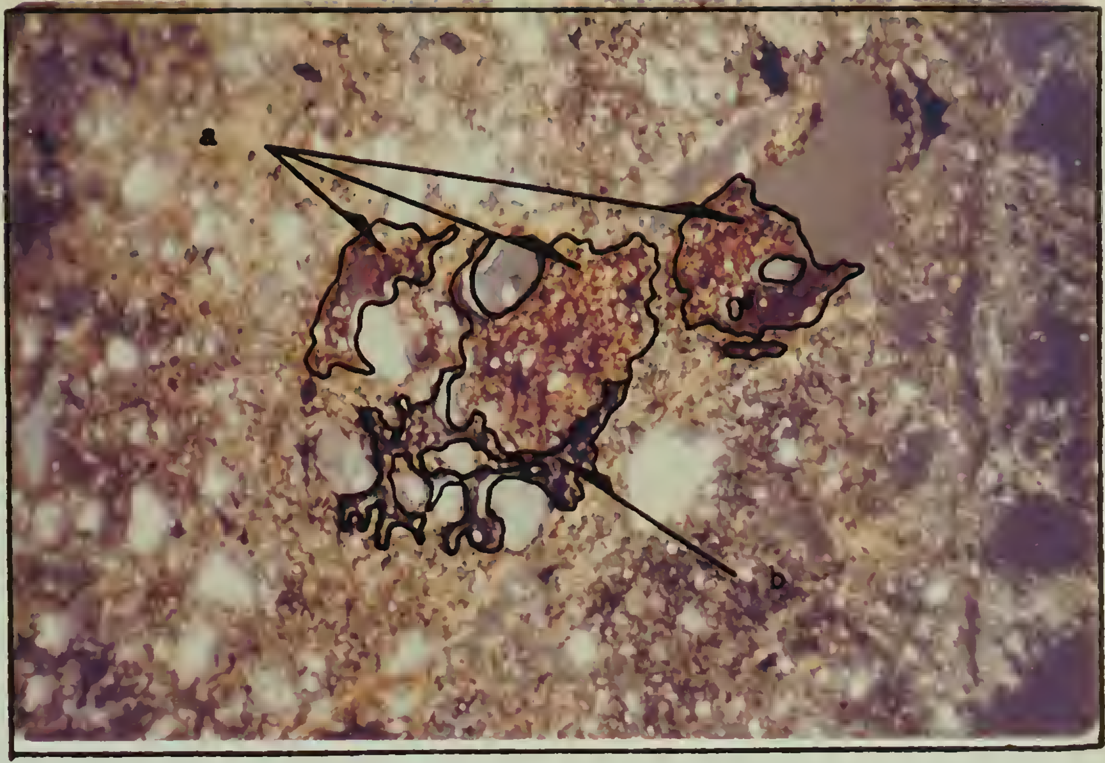


Plate 2.1 Photomicrograph of iron and organic stained plasmic materials observed in Bt_1 and Bt_2 horizons at Site 2 (partially crossed polarizers) (Site 2, Pedon 5, Bt_2 upper).

a. Iron staining
b. Organic staining

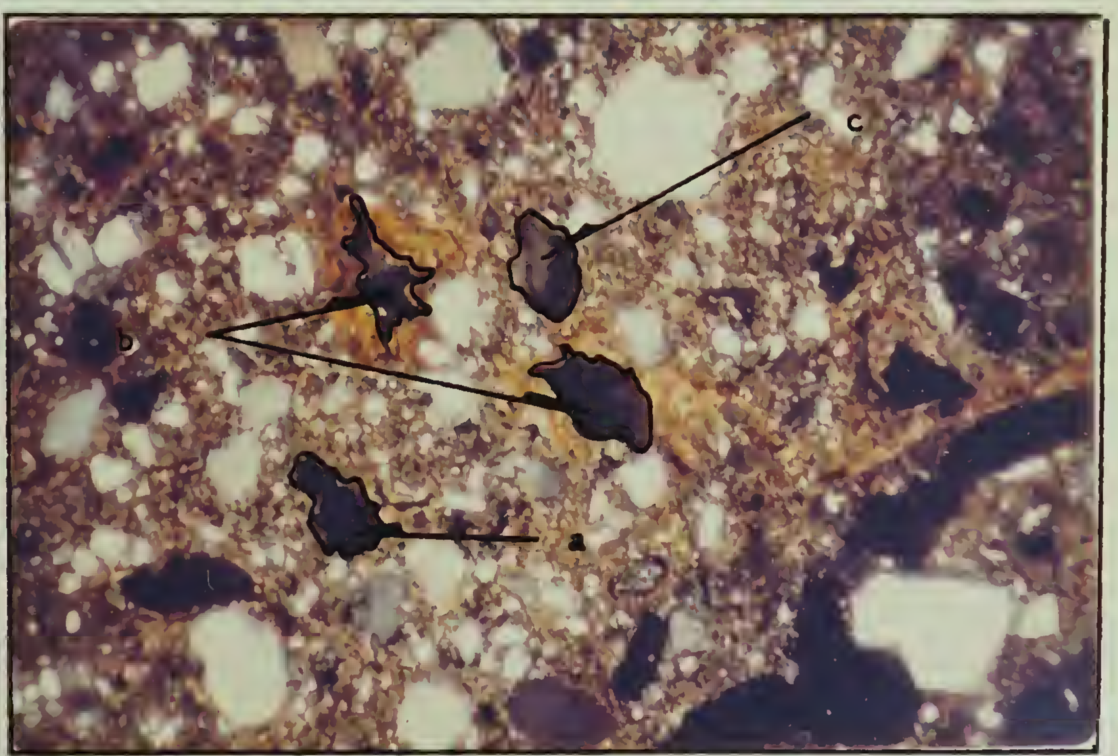
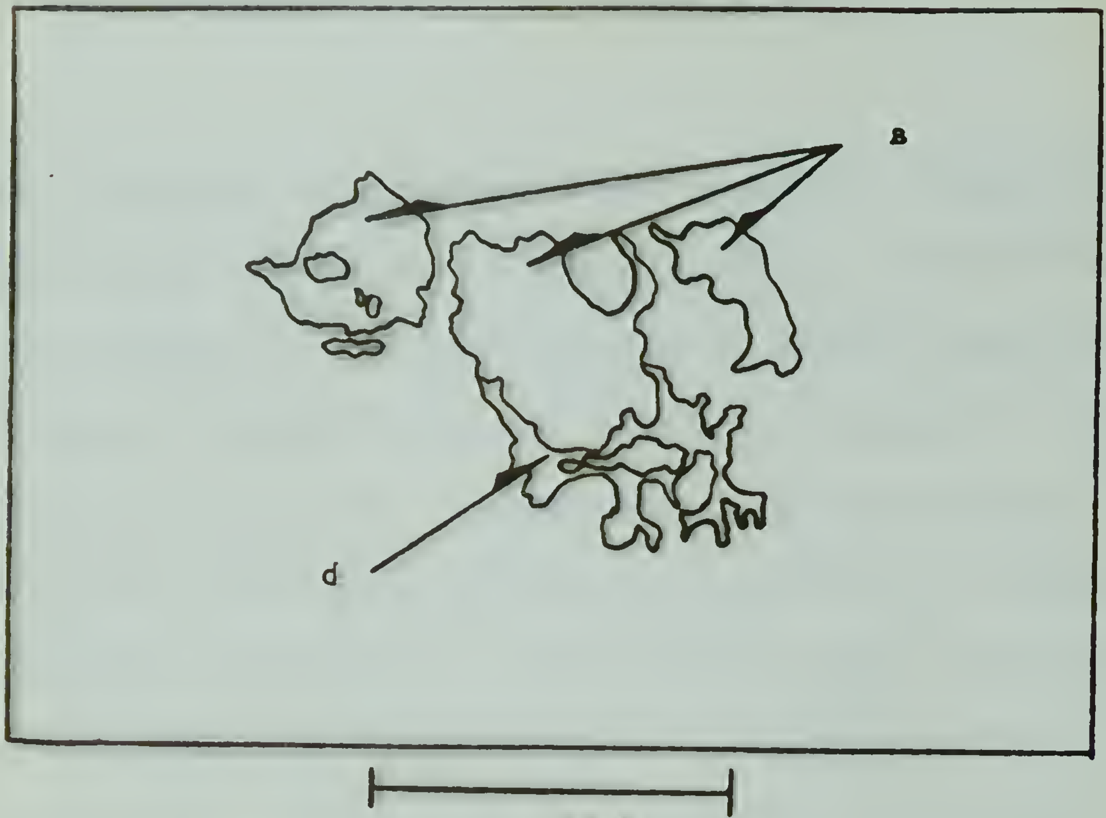


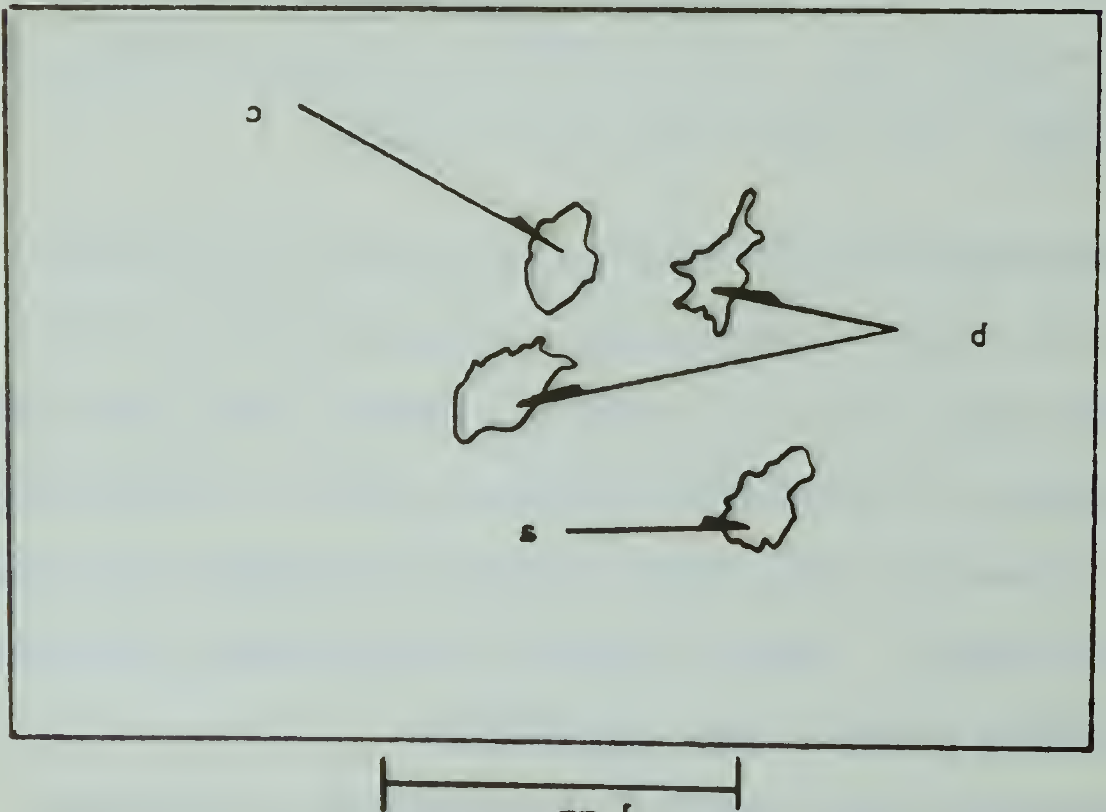
Plate 2.2 Photomicrograph of ortho and metavughs observed in Bt_1 and Bt_2 horizons (crossed polarizers) (Site 2, Pedon 1, Bt_1 upper).

a. Orthovugh
b. Metavughs
c. Skeleton



1 mm

a. Iron staining
b. Organic staining



1 mm

a. Orthovugh
b. Metavughs
c. Skeleton

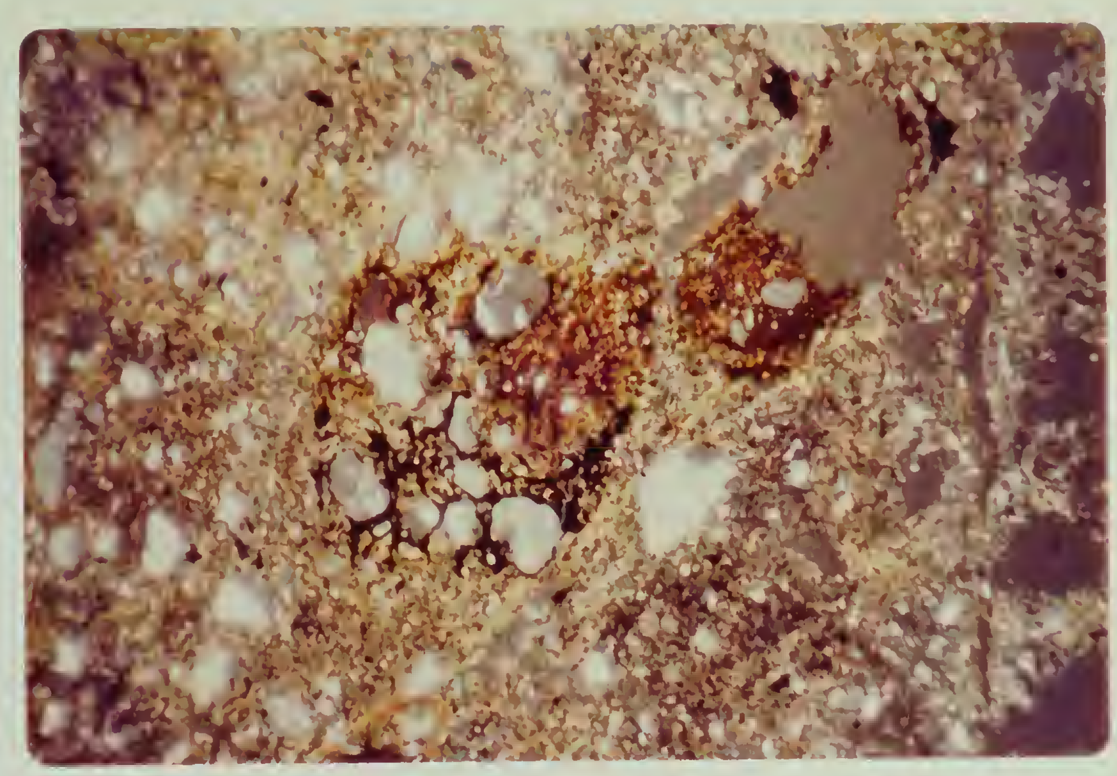


Plate 2.1 Photomicrograph of iron and organic stained plasmic materials observed in Bt_1 and Bt_2 horizons at Site 2 (partially crossed polarizers) (Site 2, Pedon 5, Bt_2 upper).

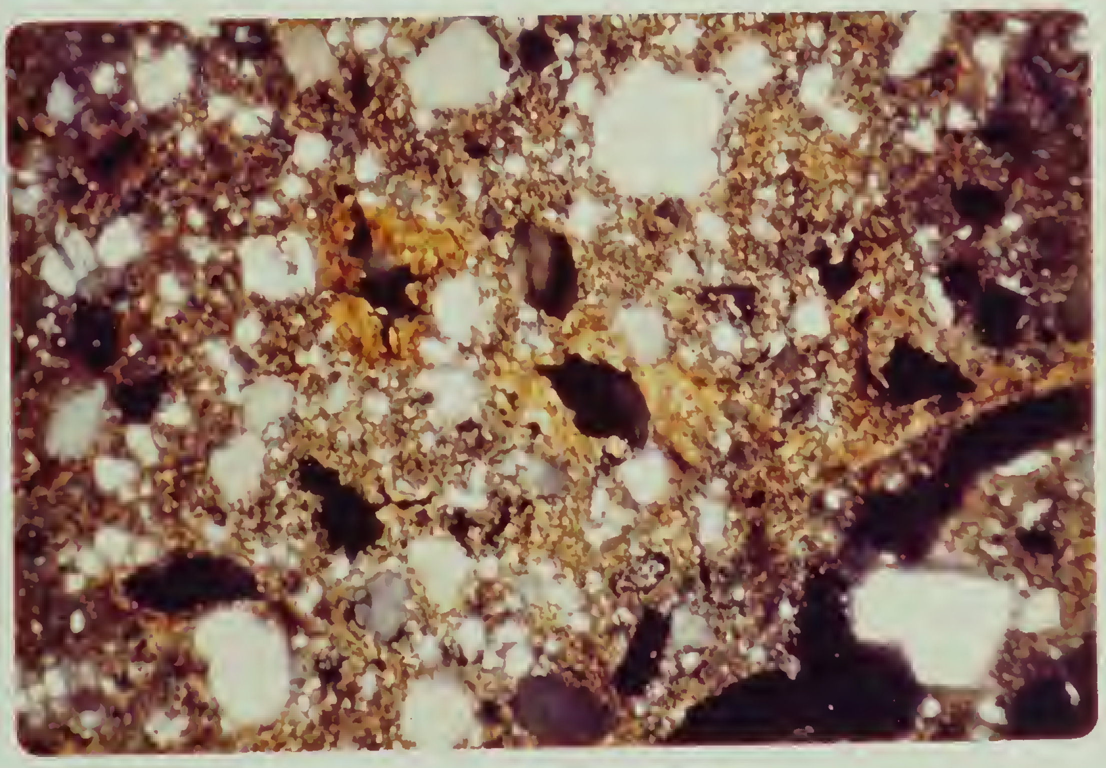


Plate 2.2 Photomicrograph of ortho and metavughs observed in Bt_1 and Bt_2 horizons (crossed polarizers) (Site 2, Pedon 1, Bt_1 upper).

upper and lower portions of the Bt_1 horizon. Orthovughs occurred (Plate 2.2) but such voids were few in number and small in areal proportion. The dimensions of the shortest axis of the metavughs were variable with a range of 25 to 1750μ.

The organic matter content of the Bt_1 horizons of these pedons was low and randomly distributed. As in the pedons of Site 1, the condition of the organic fragments ranged from intact tissues of root fragments to irregularly shaped darkened fragments. The organic fragments which appeared to be irregular in shape and darkened in color were generally associated with organic stained areas of plasma. Organic fragments appeared to be associated mostly with planar voids. Micromorphological observations within peds on Bt horizons from pedons at Site 2 revealed no root fragments completely surrounded by plasmic material.

The mineral fraction of the skeleton consisted predominantly of quartz with lesser amounts of microcline and plagioclase feldspars. Trace amounts of hornblende were also noted, which was not observed in the Bt horizons at Site 1. This difference is in agreement with results reported by Roed (1968). He suggested that Continental tills contain hornblende, whereas Cordilleran tills do not. In addition coal specks also served as members of the skeletal assemblage in these Bt horizons. The mineral grains ranged in size from 30 to 900μ at the magnification used. Chert and fragments of sandstone, siltstone and shale contributed to the bulk of the remainder of the skeleton. The sedimentary rock fragments ranged in size from 140 to 630μ in the upper segment of the horizon and from 100 to 1600μ in the lower portion. The majority of the sedimentary rocks in the upper segment appeared to be disintegrating

in that they were rounded and contained a large number of fractures. The rock fragments of the lower segment of the horizon also had a rounded appearance but with lesser fractures observable. Many of the sedimentary rock fragments of both levels were iron stained.

The plasma in the Bt_1 horizon of the pedons at Site 2 was characterized by dense packing and relative uniformity in color throughout the s-matrix. Argillans in the upper portion of the Bt_1 horizon were the most distinctive of those observed in either the Bt_1 or Bt_2 horizon of these pedons (Plate 3.1). These argillans were variable in thickness from less than 8μ to 107μ. The dominant cutanic feature observed in the horizon was skew plane argillans which had a strong, continuous, orientation parallel to the faces of peds. These argillans were characterized by a sharp boundary and were strongly separated in most instances. Metavugh argillans with strong, continuous, parallel orientation, sharp boundaries and strong separation occurred commonly in intrapedal voids (Plate 2.2). The length, thickness and degree of continuity of the cutanic surfaces observed in voids presented considerable contrast to similar features discussed in Bt horizons at Site 1. Some sedimentary rock fragments had embedded grain cutans weakly oriented with a weak boundary and poor separation suggesting possible in situ formation due to decomposition of the rock fragments. Occasional embedded grain argillans, weakly separated around mineral grains and chert fragments with strong but discontinuous parallel orientation and weak boundaries occurred sporadically. These cutanic features were observed for the most part in the upper portion of the horizon. This again is in contrast to the Bt horizons of Site 1 in which the plasmic fabric was

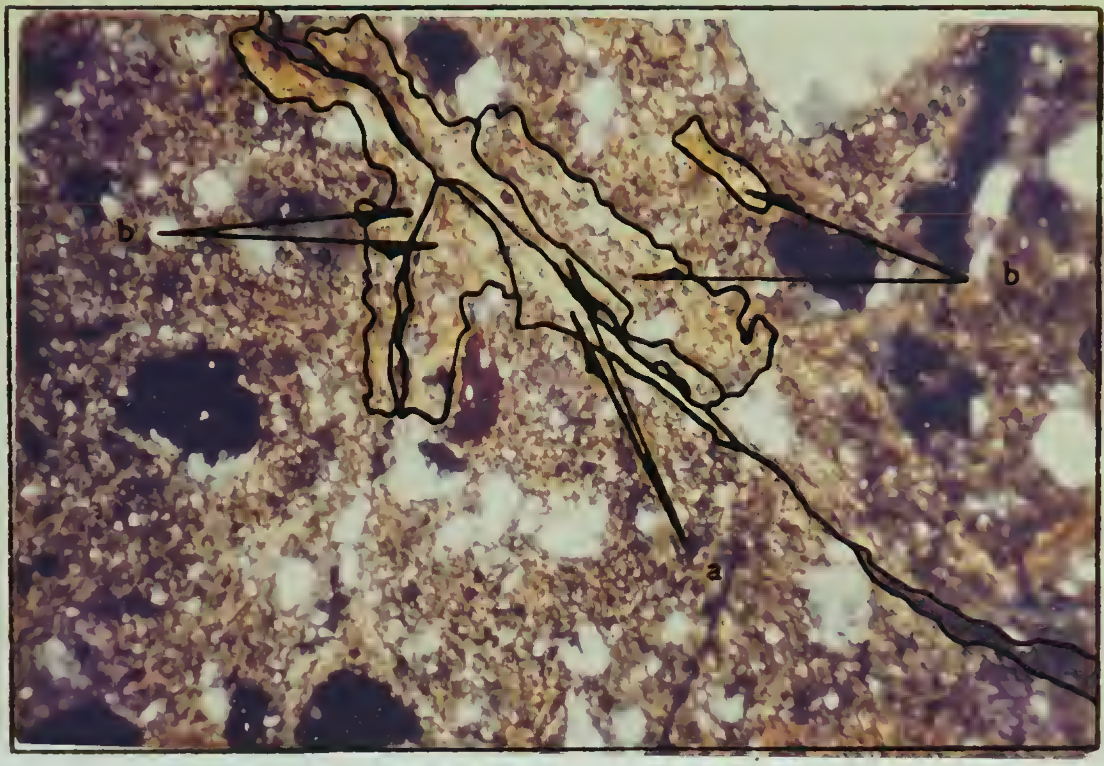


Plate 3.1 Photomicrograph of skew plane argillans with associated plasmic separations in the form of oriented striations (crossed polarizers) (Site 2, Pedon 5, Bt_1 upper)

a. **Argillan**

b. **Plasma separations**

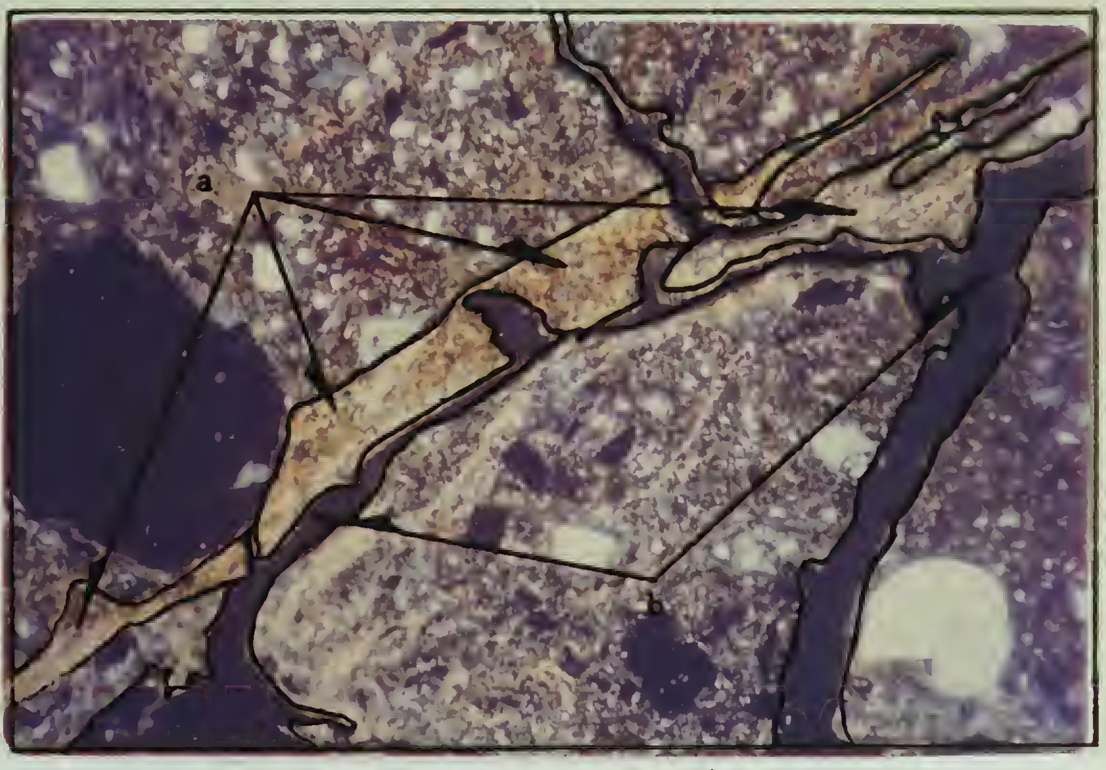
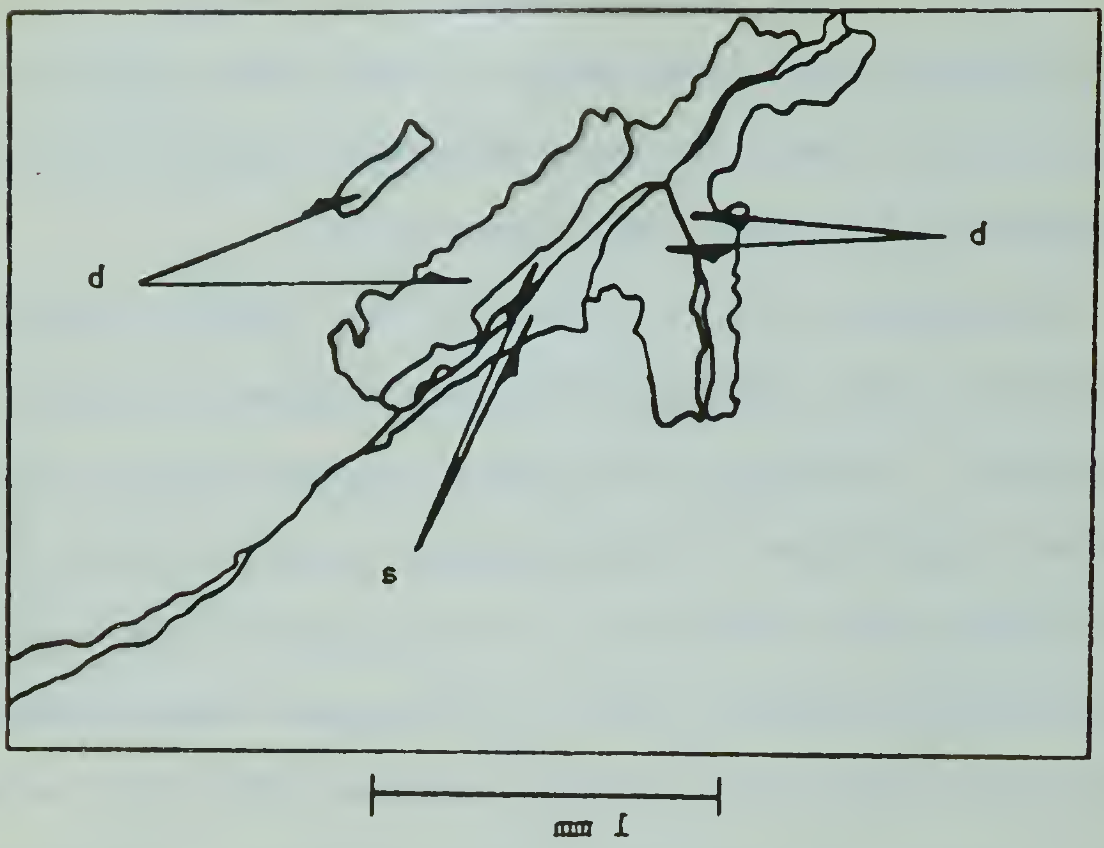


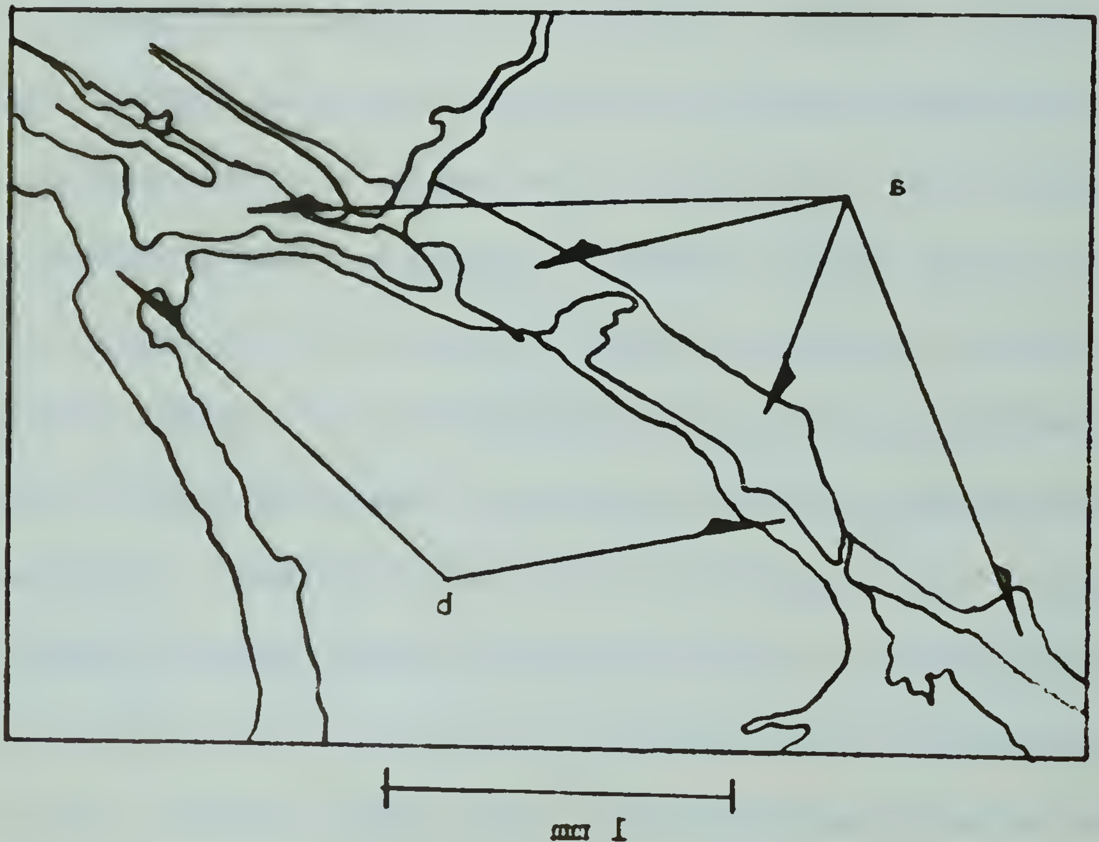
Plate 3.2 Photomicrograph of a plasma separation (slickenside). Note abundance of striated clays with parallel orientation (crossed polarizers). (Site 2, Pedon 5, Bt_2 upper).

a. **Slickenside**

b. **Planes**



a. Argillan
b. Plasma separations



a. Slickenside
b. Planes

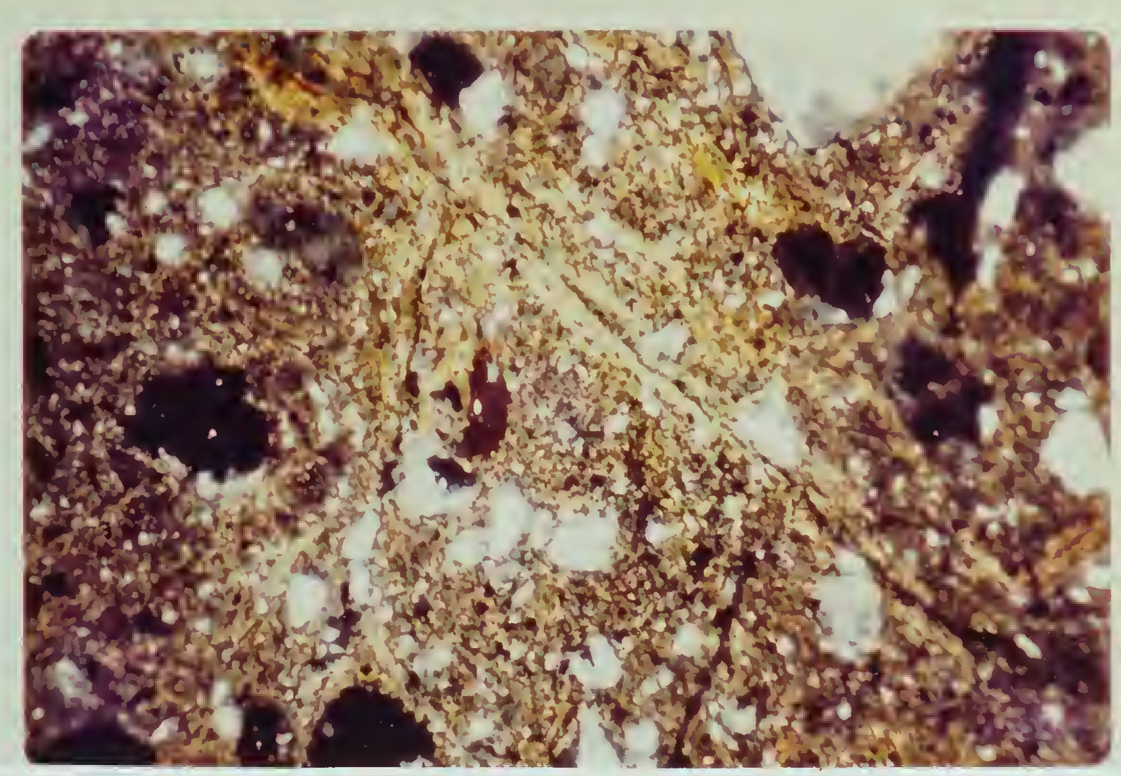


Plate 3.1 Photomicrograph of skew plane argillans with associated plasmic separations in the form of oriented striations (crossed polarizers) (Site 2, Pedon 5, Bt_1 upper)

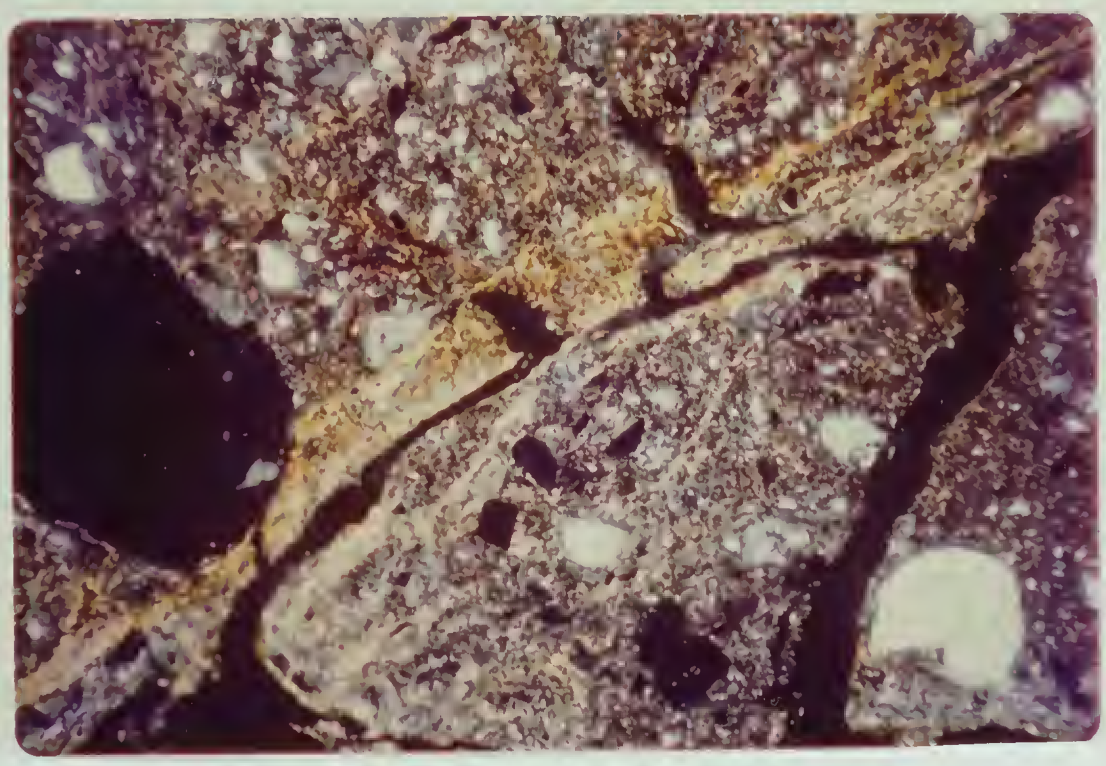


Plate 3.2 Photomicrograph of a plasma separation (slickenside). Note abundance of striated clays with parallel orientation (crossed polarizers). (Site 2, Pedon 5, Bt_2 upper).

dominated by embedded grain argillans.

A large number of plasma separations were observed in these Bt_1 horizons with the majority in the lower portion. These consisted of striated zones of variable length composed of clay minerals with parallel orientation. The boundaries of these plasma separations were in most cases sharp and they appeared strongly separated. The plasma separations in the lower portion of the Bt_1 formed fairly complex networks of linear arrays parallel to voids and other plasma separations (Plate 3.2). Plasma separations may be interpreted as one indication of stress cutans corresponding to the observed "slickensides" noted in the morphological characterization of pedons. Brewer (1964a) suggests that stress cutans are usually associated with planar voids, as was the case in these thin sections (Plate 3.2). Brewer also asserts that stress cutans typically have associated with them a striated orientation of subcutanic plasma, such as the observed plasma separations.

Nodules (Plate 3.1) occurred randomly in both upper and lower sections of the horizon. These nodules were characterized by an irregular shape and diffuse periphery in the majority of cases and appeared under reflected light to be iron concretions. Some however were heavily organic stained areas or areas of mixed iron and organic staining.

The plasmic fabric of the Bt_1 horizon of pedons at Site 2 varied between the upper and lower portion of the horizon but not to the degree observed at Site 1. The fabric of the upper portion of the horizon was vosepic with some local areas which could be termed skel-vosepic. The fabric of the lower segment was ma-vosepic. The skeletal arrangement in both cases was random.

The upper and lower sections of the Bt_2 horizons from the five pedons consisted of a gray brown plasma densely packed about the skeleton. Mottles appeared randomly distributed and organic stained areas of plasma were generally associated with pore space.

Aggregation in the upper portion of the Bt_2 horizon was dominated by moderately well defined, subrounded blocky, accommodated primary peds larger than the peds in the Bt_1 horizon in most cases. A greater number of these peds coalesced to moderately defined, subrounded blocky, accommodated secondary peds than was observed in the Bt_1 horizon. The lower portion of the Bt_2 horizon consisted of very large, well defined, subrounded blocky, accommodated secondary peds. A few subrounded blocky, accommodated primary peds also existed. The packing arrangement of peds in this horizon was regular in all cases.

Pore space in the Bt_2 horizon was dominated by interpedal voids, predominately skew planes, interconnected, with smoothed walls. Occasionally these planar voids were longer and more linear than those observed in the Bt_1 horizon. The majority were shorter and not as continuous, forming irregular networks associated with secondary and/or tertiary peds. Due to larger ped size the proportion of these interpedal voids decreased from that observed in the Bt_1 horizon.

Intrapedal voids, the majority of which were metavughs, were randomly distributed in the s-matrix and varied in size from 20 to 600μ. Orthovughs constituted a very small proportion of the total pore space.

The amount of organic matter was small and together with the occurrence of nodules, appeared unchanged from the observed features in the Bt_1 horizon. Similarly the mineral fraction of the skeleton was

unchanged with regard to species and possessed dimensions ranging from 20 to 500μ. Chert fragments, coal fragments and rounded sedimentary rock fragments constituted the remainder of the skeletal materials. The sedimentary rock fragments (0.1 mm to 2.3 mm) in the Bt_2 horizon were iron stained and fractured in the majority of cases. Fractures appeared less numerous than in the Bt_1 horizon, suggesting a lesser degree of in situ weathering.

Argillans were observed in the upper and lower segments of the Bt_2 horizon with dimensions of less than 8μ to 70μ and less than 8μ to 40μ, respectively. As in the Bt_1 horizon the dominant cutanic features in the upper portion were skew plane argillans with strong, continuous, parallel orientation on the faces of peds. These argillans were characterized by sharp boundaries and a strong separation in most cases and were observed to be less predominant in the lower portion. Metavugh argillans with strong, continuous, parallel orientation, sharp boundaries and strong separation occurred frequently in intrapedal voids in both sections of the horizon. Unlike the plane argillans, metavugh argillans did not appear to change in occurrence or degree of development with increasing depth. Some sedimentary rock fragments had embedded grain cutans with weak orientation, weak boundaries and poor separation suggesting in situ formation as observed in the Bt_1 horizon. As was observed in the lower section of Bt_1 horizons, a small number of embedded grain argillans, weakly separated around mineral grains and chert fragments with strong, discontinuous, parallel orientation and weak boundaries appeared randomly distributed.

Plasma separations were numerous in the Bt_2 horizon and reached

a maximum areal proportion in the lower section. As observed in the Bt_1 horizon these plasma separations consisted of striated zones of variable length, composed of parallel-oriented clay-sized particles. The boundary of these striated zones was sharp and strongly separated. Complex networks of parallel striations were observed in the s-matrix and were, in most cases, parallel to planar voids (Plate 3.2).

The plasmic fabric of the Bt_2 horizons in pedons examined from Site 2 was ma-vosepic in both the upper and lower portions. The skeletal arrangement in the horizons was random.

Micromorphological observations of Bt horizons from pedons at Site 2 suggest a different interpretation as to possible processes of pedogenesis than in Bt horizons from Site 1. The predominant strongly oriented void argillans are generally considered indicative of illuviation (Brewer, 1964a) and suggest it to be the predominant pedogenic process in these Bt horizons. Additional support is given this proposal by the sharpness of boundary between cutans and noncutanic material. The development with respect to depth of cutans is also indicative of illuviation, with the greatest proportion of cutans at the top of the Bt_1 and a decreasing proportion with increasing depth, similar to observations of Gillespie and Elrick (1968). The plasma separations which are very distinctive in these Bt horizons are generally attributed to stress (Brewer, 1964a; Day and Holmgren, 1952) or to wetting and drying (Stephen, 1960). Stresses could also result from overburden pressures and freeze-thaw cycling on soil materials of this texture.

Site 3

Field observations and laboratory analyses of the five pedons characterized at Site 3 established the existence of three Bt horizons in each profile. Each of these horizons was examined microscopically at the upper and lower levels in duplicate thin sections. The plasma of the three Bt horizons was a relatively uniform dark gray brown color with an abundance of darker areas due to iron and organic staining. The density of packing of plasma around skeleton grains was comparable to the dense packing reported for the Bt horizons of pedons from Site 2.

The dominant form of aggregation in the Bt_1 horizon was very well defined, subrounded blocky (equant polyspheric), accommodated peds which had a regular packing arrangement (Plate 4.1). These primary peds were smaller than those observed at Site 2 and increased in size with increasing depth. The proportion of these primary aggregates that coalesced to less well defined subrounded blocky, accommodated, secondary peds also increased in the lower section of the horizon. The packing arrangement of peds became more regular with depth.

As was observed in Site 2 pedons, the majority of the pore area in thin sections from these Bt_1 horizons was in the form of interpedal interconnected planar voids. Due to smaller ped size the skew and craze planes were shorter than observed for the Bt_1 horizons at the other two sites and the walls were not as smooth due to a lesser amount of cutanic surfaces. In the majority of cases these planes formed an irregular network which in some cases was complex. Intrapedal voids in the form of ortho- and metavughs (dimensions 40 to 800μ) existed randomly in the s-matrix in both the upper and lower segments of the

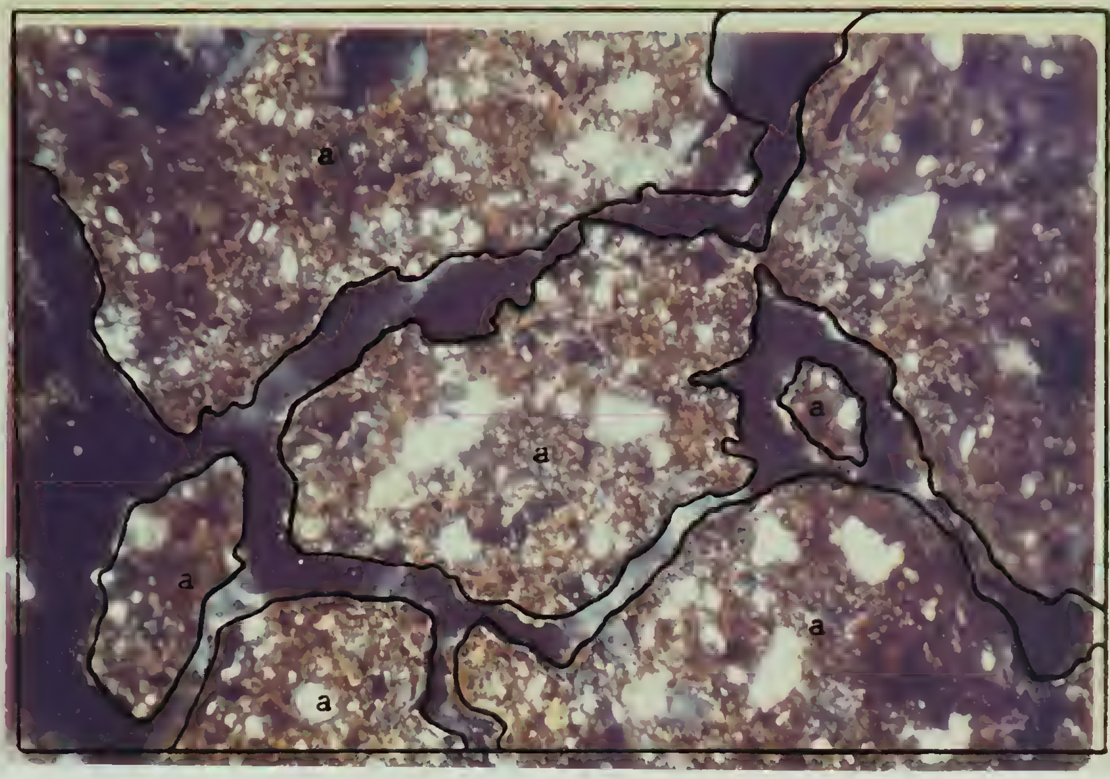


Plate 4.1 Photomicrograph of regular packing arrangement of very well defined, subrounded blocky primary peds (crossed polarizers) (Site 3, Pedon 2, Bt_1 upper).

a. Primary peds

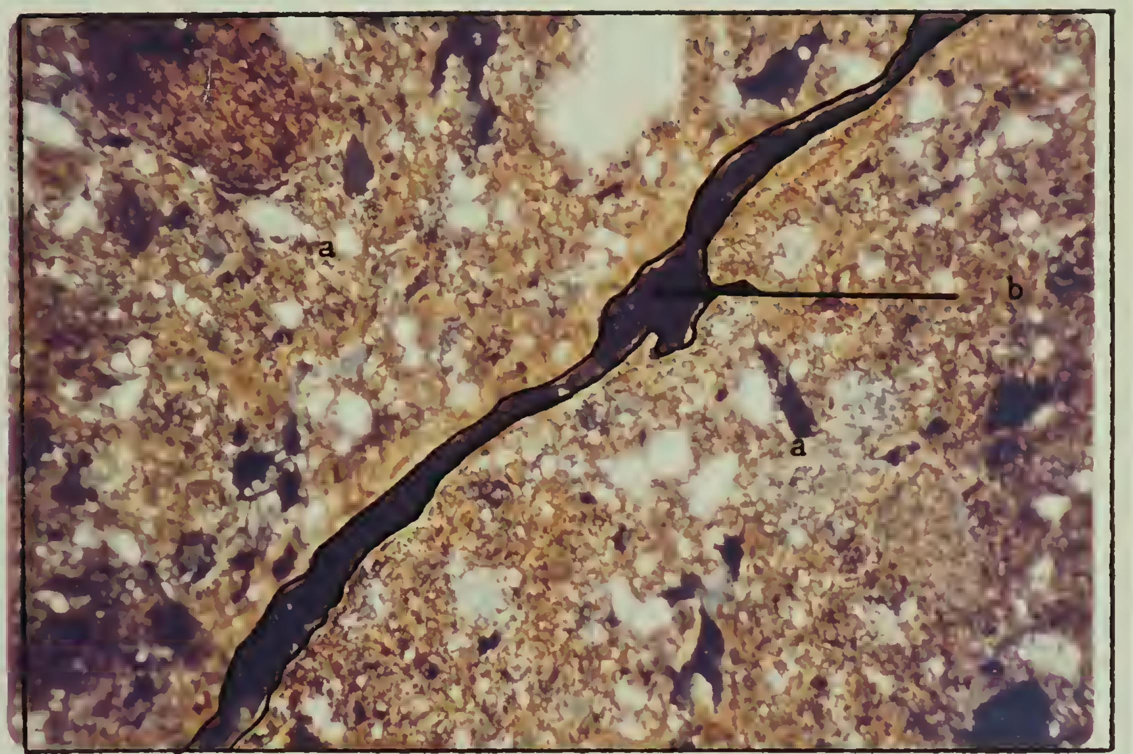
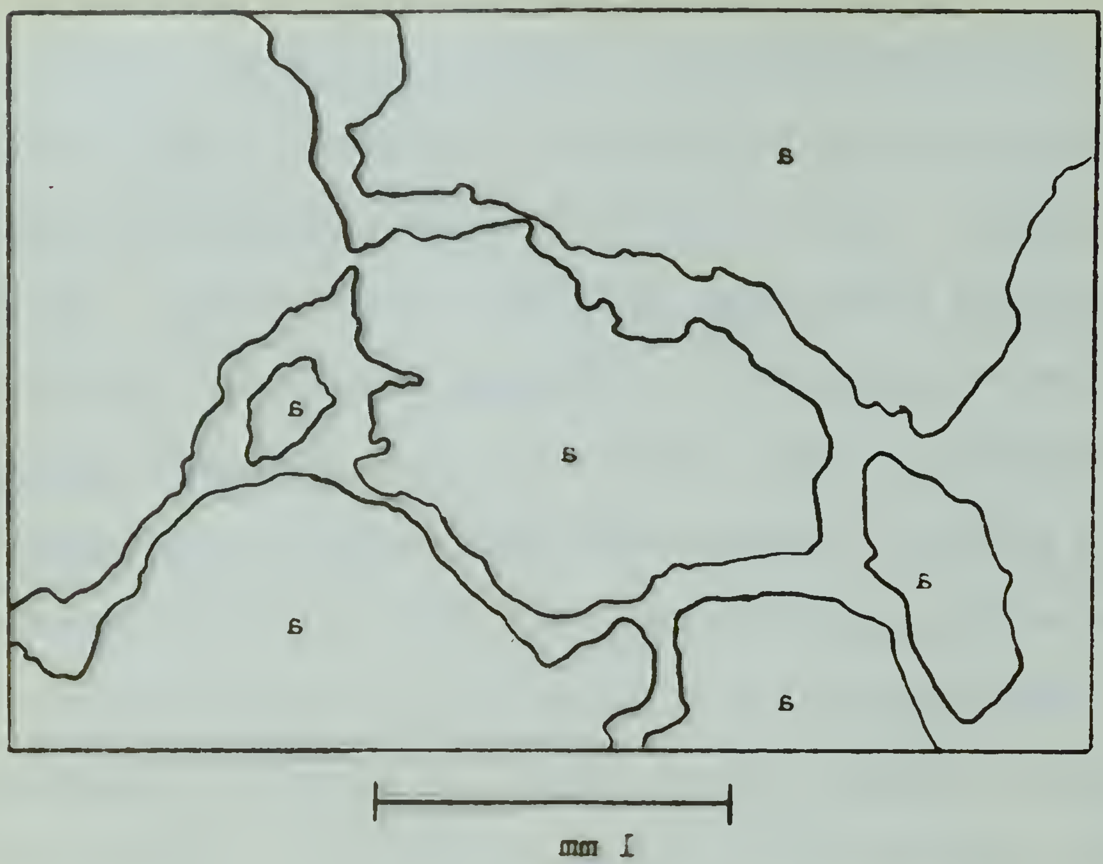


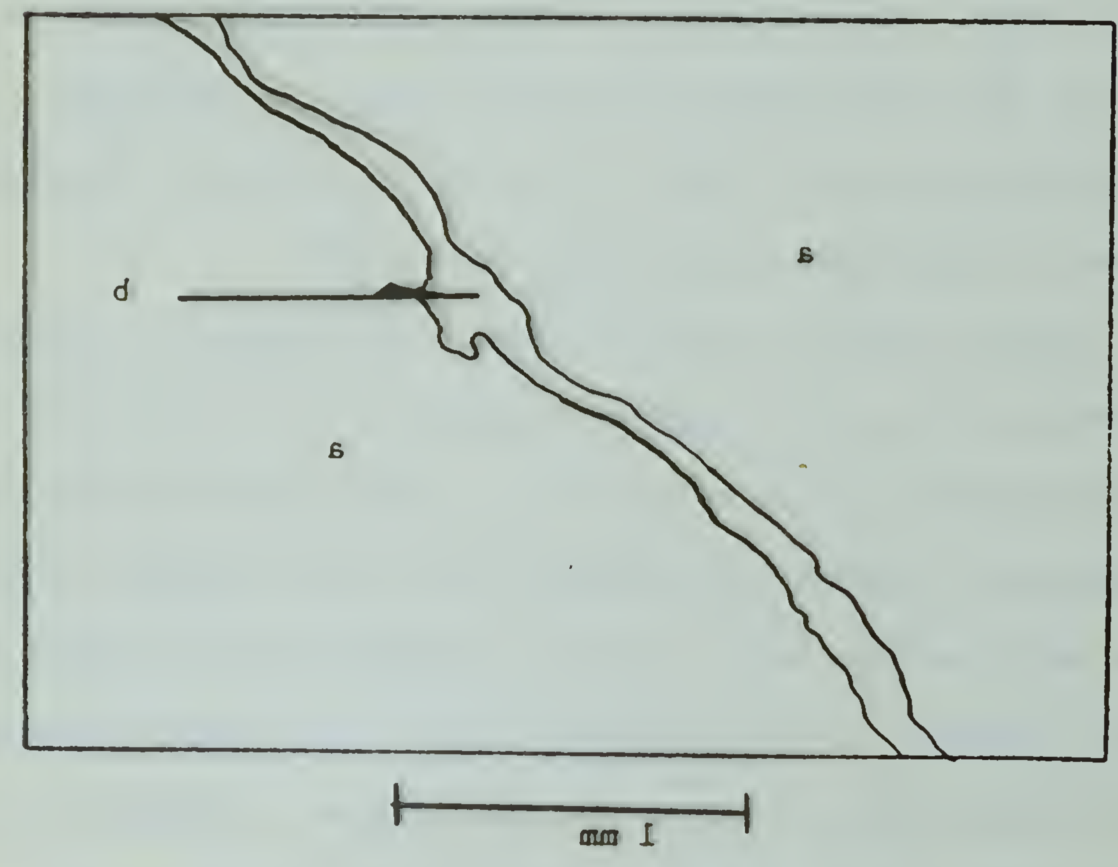
Plate 4.2 Photomicrograph depicting large primary peds as compared to Plate 4.1. Note meta-skew-plane traversing photomicrograph (crossed polarizers) (Site 3, Pedon 1, Bt_2 bottom).

a. Large primary peds

b. Meta-skew-plane



a. Primary peds



a. Large primary peds
b. Meta-skew-plane

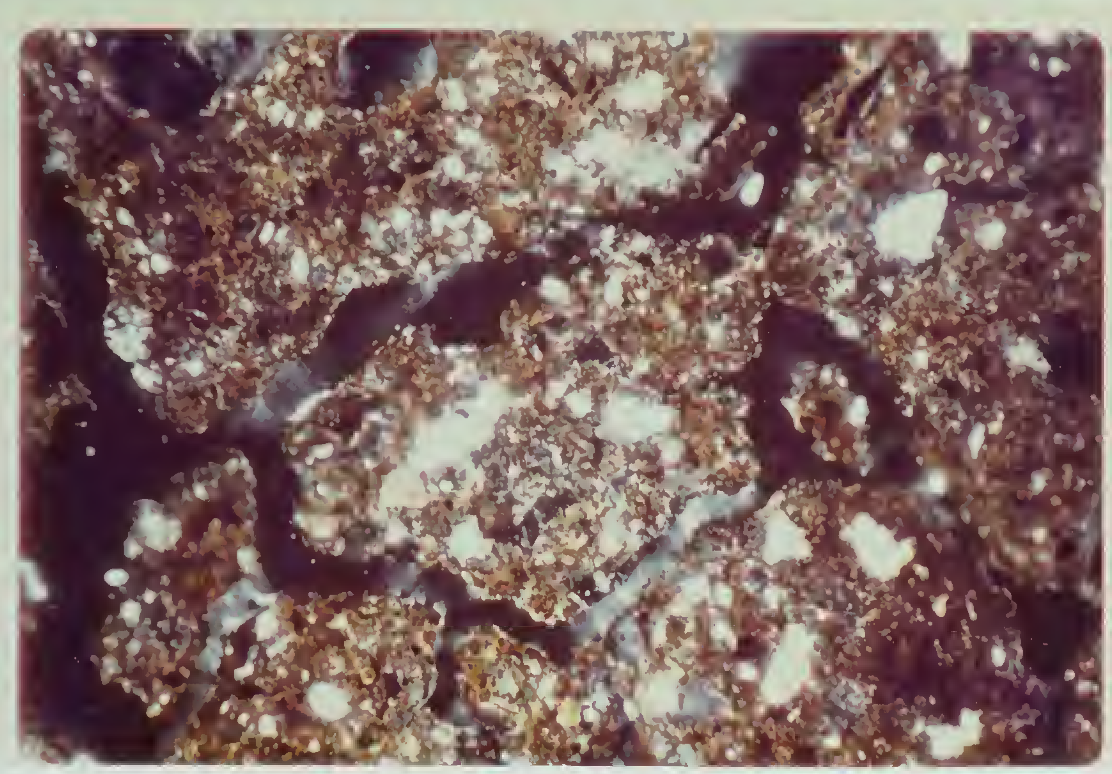


Plate 4.1 Photomicrograph of regular packing arrangement of very well defined, subrounded blocky primary peds (crossed polarizers) (Site 3, Pedon 2, Bt_1 upper).

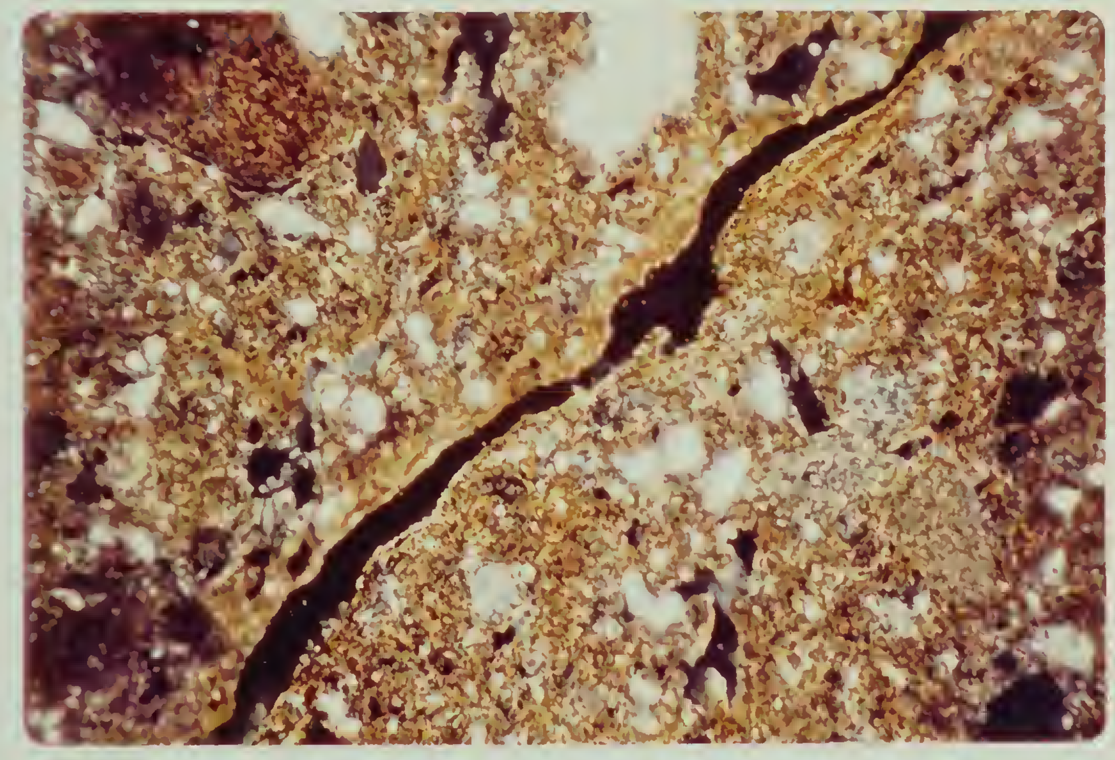


Plate 4.2 Photomicrograph depicting large primary peds as compared to Plate 4.1. Note meta-skew-plane traversing photomicrograph (crossed polarizers) (Site 3, Pedon 1, Bt_2 bottom).

horizon.

The organic fraction of the three Bt horizons was, by visual observation, the same as that for Bt horizons at Site 2 with the exception of occasional root fragments which were within peds and encased in plasmic material. Organic fragments were generally fairly well decomposed and were associated with organic stained areas of plasma.

The skeletal fraction of the s-matrix of the Bt_1 horizon was similar to that observed at Site 2, with the mineral portion consisting mainly of quartz with lesser amounts of microcline and plagioclase feldspars and occasional hornblende (dimensions of mineral skeleton 20 to 750μ). Fragments of chert, coal and sedimentary rocks existed randomly, with the dimensions of the rounded, iron stained, fractured and weathered rock fragments ranging from 84 to 2300μ. Weathering of these rock fragments was interpreted from large fractures within and diffuse areas about their periphery.

The densely packed and relatively uniform plasma in the upper and lower segments of Bt_1 horizons possessed a comparatively small areal proportion of cutanic features in the form of thin (less than 8 to 40μ) argillans. Skew and craze plane argillans being moderately strong to strong, discontinuous and oriented parallel to ped surfaces were limited in extent. Due to the thin nature of these argillans the sharpness of boundary in thin section appeared less than that observed in Bt horizons at Site 2. At higher magnifications (120x) these argillans appeared strongly separated in the majority of cases. Metavugh argillans were variable in the Bt_1 horizon with moderately strong to strong, discontinuous to continuous parallel orientation, weak to sharp boundaries and

strong separation. Metavugh argillans in the lower section of the horizon were in general more abundant, thicker and more continuous than plane argillans in either portion and vugh argillans in the upper section. The most continuous and thickest of these vugh argillans were associated with skeletal members on void walls. As was observed in pedons at Site 2 some sedimentary rock fragments had embedded grain cutans with poorly to moderately well defined parallel orientation, a weak boundary and poor separation, but no embedded grain argillans associated with minerals were observed. The dominant plasmic feature in this horizon was a large number of plasma separations which consisted of striated zones of variable length with strong parallel orientation and a random distribution pattern.

Small, irregular nodules which appeared under reflected light to be iron concretions existed randomly in the three Bt horizons examined from each pedon.

The plasmic fabric of the Bt_1 horizon in pedons examined at Site 3 was masepic with a few local areas that are best termed vo-masepic. The skeletal distribution in all cases was random.

Aggregation in Bt_2 horizons observed in pedons 1 to 4 inclusive was dominated by primary peds larger than those in the Bt_1 horizon. The portion of these well defined, subrounded blocky, accommodated primary peds that coalesced to less well defined, subrounded blocky, accommodated secondary peds was larger than observed in Bt_1 horizons, similar to the trend observed at Site 2. Thin sections from Bt_2 horizons in pedon 5 were an exception to the trend. Well defined, subrounded blocky, accommodated secondary peds were the dominant form of aggregation with a very

small proportion of primary peds. The size of primary and secondary peds, in general, increased with depth and a regular packing arrangement was observed in all cases.

Pore area in thin section consisted, for the most part, of interpedal voids in the form of skew and craze planes of lesser abundance than in Bt_1 horizons due to larger aggregates (Plate 4.2). These planar voids were characterized as interconnected planes with smoothed walls. The general trend as observed in Site 2 was for longer, more linear planar voids between peds than in the Bt_1, with smoothed walls due to an increase in the occurrence of cutanic features. A large number of short discontinuous craze planes existed as well, associated with secondary peds especially in pedon 5. The development of irregular networks of planes decreased in areal proportion from that observed in the Bt_1. Intrapedal voids in the form of ortho- and metavughs (Plate 5.1) existed randomly in the s-matrix in both the upper and lower segments of the Bt_2 horizon with dimensions ranging from 60 to 600μ.

The skeletal fraction of the s-matrix appeared unchanged from the observations reported for the Bt_1 horizon with the exception of a lesser number of fractures in the rounded sedimentary rock fragments (Plate 5.2) which had dimensions ranging from 60 to 3000μ.

Argillans in the upper and lower segments of the Bt_2 horizon appeared greater in areal proportion than in the Bt_1 horizon with a range of thickness from less than 8 to 70μ in the upper portion and from less than 8 to 110μ in the lower portion. Skew and craze plane argillans with strong parallel orientation and greater continuity than plane argillans in the Bt_1 horizon (Plate 4.2) were associated with ped

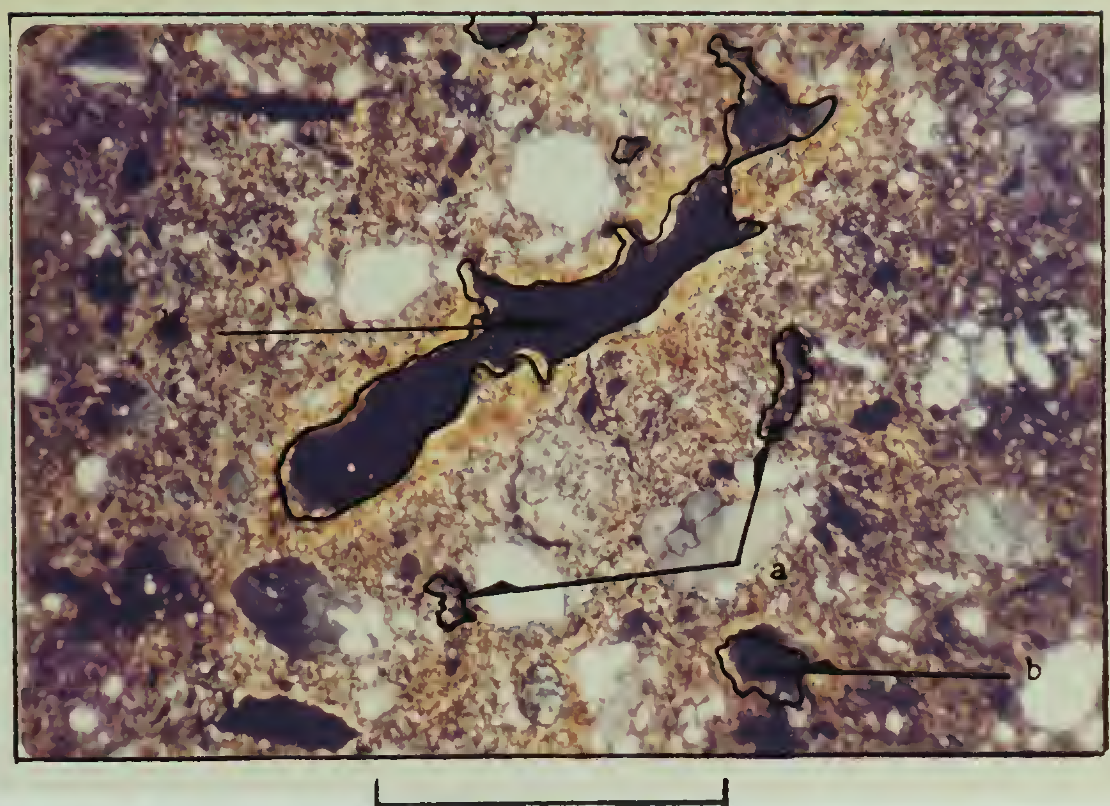


Plate 5.1 Photomicrograph of ortho- and metavughs (crossed polarizers) (Site 3, Pedon 1, Bt_2 bottom).

a. Orthovughs

b. Metavughs

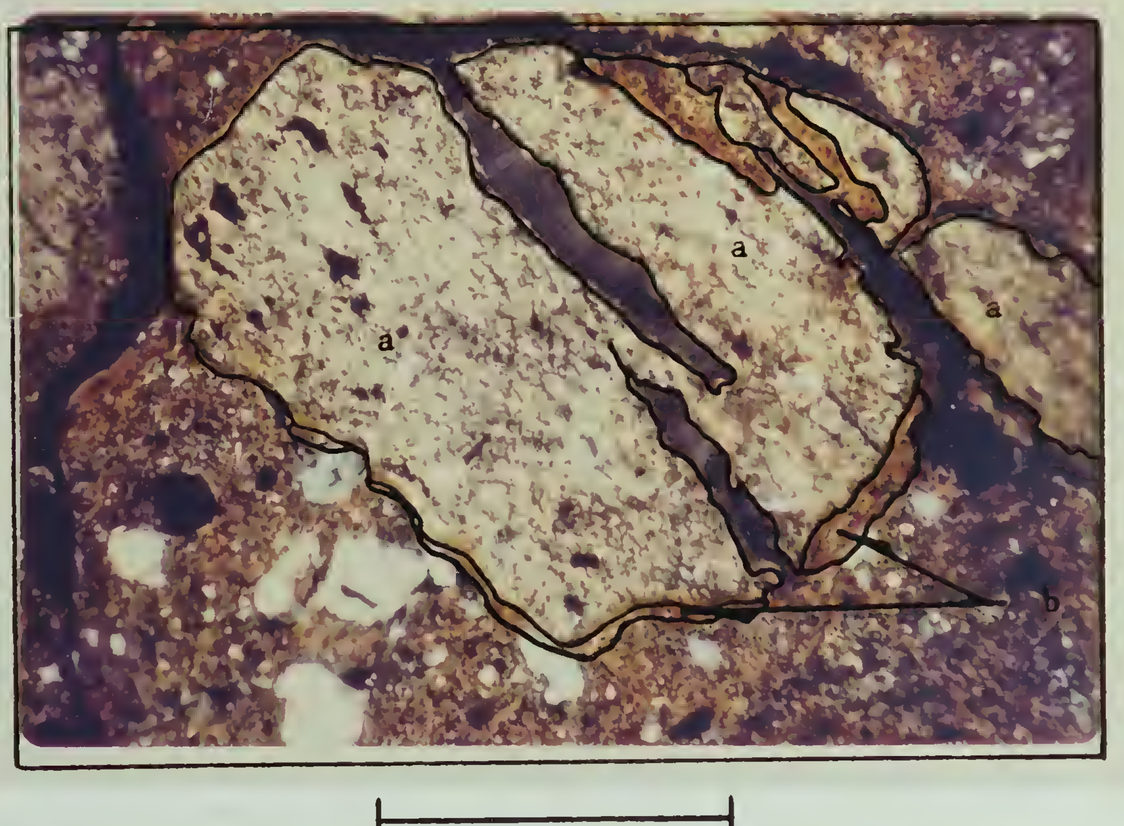
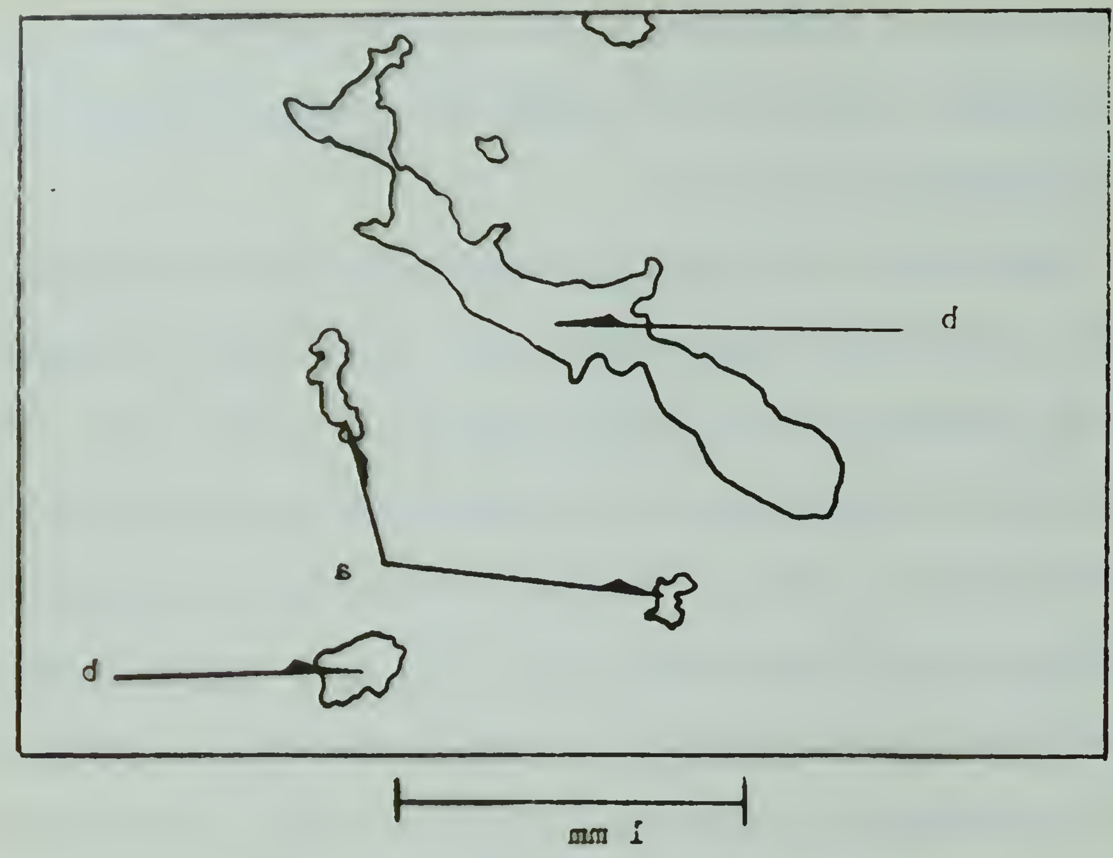


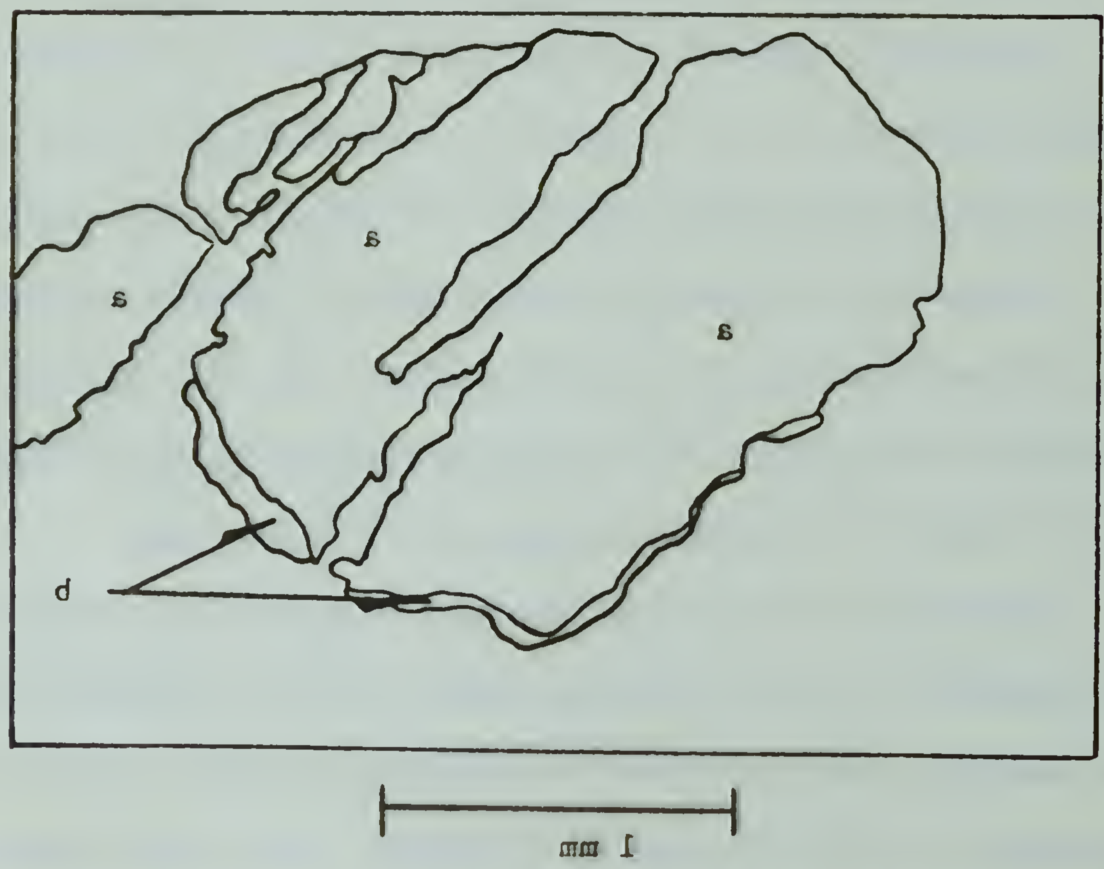
Plate 5.2 Photomicrograph of sedimentary rock fragment displaying fractures and stained areas. Note thin embedded grain cutans (crossed polarizers) (Site 3, Pedon 2, Bt_2 upper).

a. Rock fragment

b. Embedded grain cutan



a. Orthovughs
b. Metavughs



a. Rock fragment
b. Embedded grain cutan

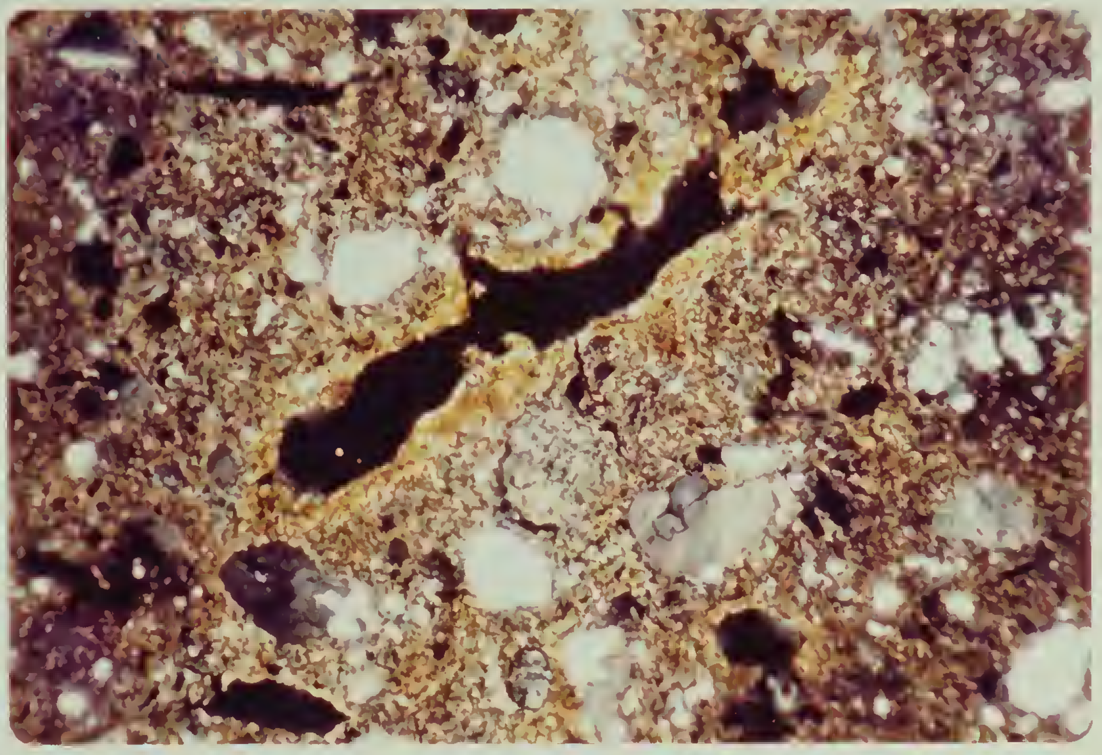


Plate 5.1 Photomicrograph of ortho- and metavughs (crossed polarizers) (Site 3, Pedon 1, Bt_2 bottom).

Plate 5.2 Photomicrograph of sedimentary rock fragment displaying fractures and stained areas. Note thin embedded grain cutans (crossed polarizers) (Site 3, Pedon 2, Bt_2 upper).

surfaces by a sharp boundary with the exception of pedon 5. Plane argillans in pedon 5 were poorly defined, very thin and discontinuous. Metavugh argillans were variable from strong, discontinuous to continuous with parallel orientation, sharp boundaries and strong separation (Plate 5.1). Some sedimentary rock fragments had embedded grain cutans with poorly to moderately well defined orientation, weak boundaries and poor separation (Plate 5.2). As was the case in the Bt_1 horizons, plasma separations consisting of striated zones of variable length of oriented clays existed within the s-matrix. The occurrence of plasma separations appeared to be greater than in the Bt_1 horizon with the exception of pedon 5. The proportion of the striated zones increased from the upper to the lower level of the horizon with an increasing tendency to parallel groupings.

The plasmic fabric of the Bt_2 horizon in pedons 1 to 4 was ma-vosepic in both the upper and lower levels, with a greater degree of development in the lower portion. The fabric of the Bt_2 horizon of pedon 5 is best described as weakly vo-masepic. The skeletal distribution in all instances was random.

Aggregation in the upper section of Bt_3 horizons in pedons 1 to 4 inclusive, was generally in the form of large, poorly defined, sub-rounded blocky, accommodated primary peds that coalesced to poorly defined, subrounded blocky, accommodated secondary peds. Aggregation in the lower portion of the Bt_3 horizon consisted of very large poorly defined, subrounded blocky, accommodated secondary peds, the majority of which coalesced to tertiary peds. The Bt_3 horizon of pedon 5 revealed, for the most part, no form of aggregation (Plate 6.1). Some very large

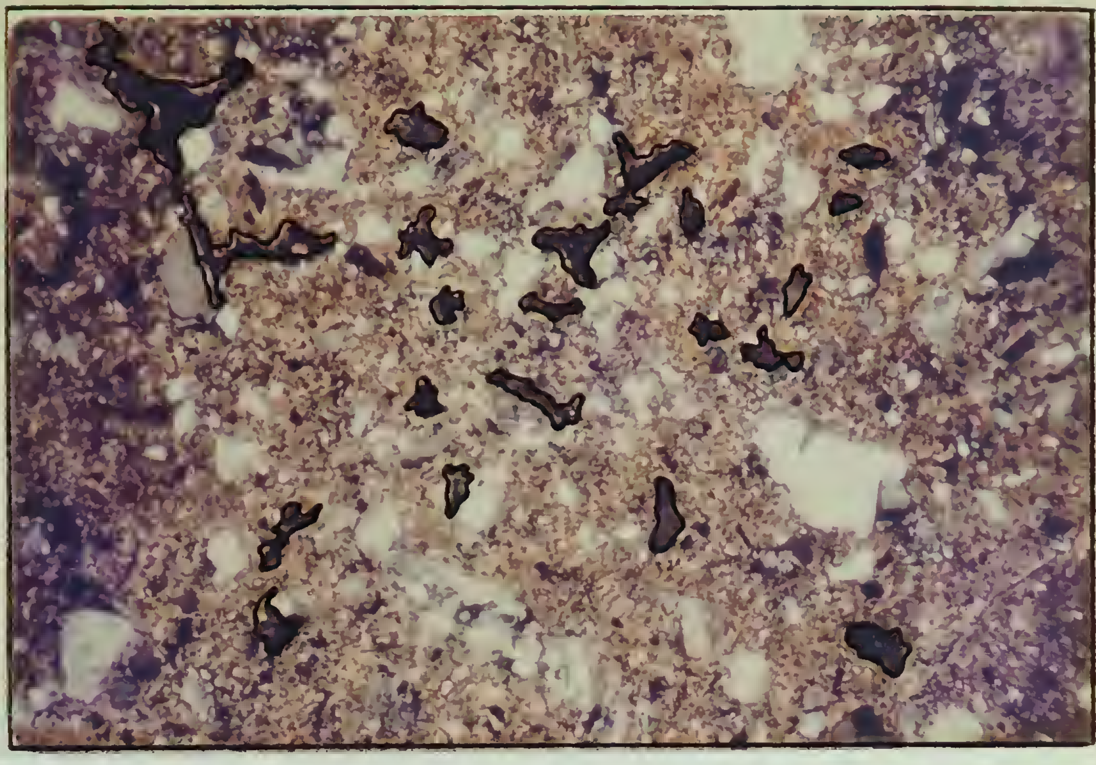
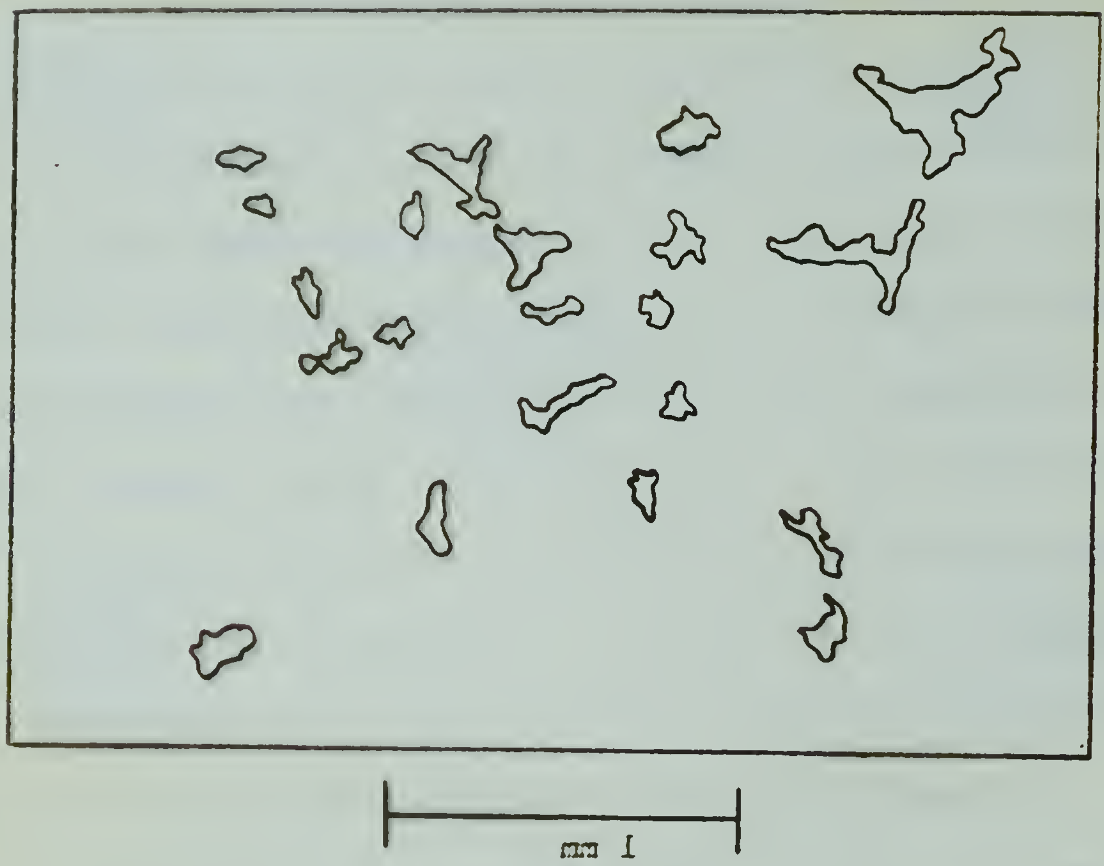


Plate 6.1 Photomicrograph of argillasepic plasmic fabric in lower portion of Bt_3 horizon of Pedon 5 at Site 3 (crossed polarizers).

All areas outlined pepresent voids



All areas outlined represent voids

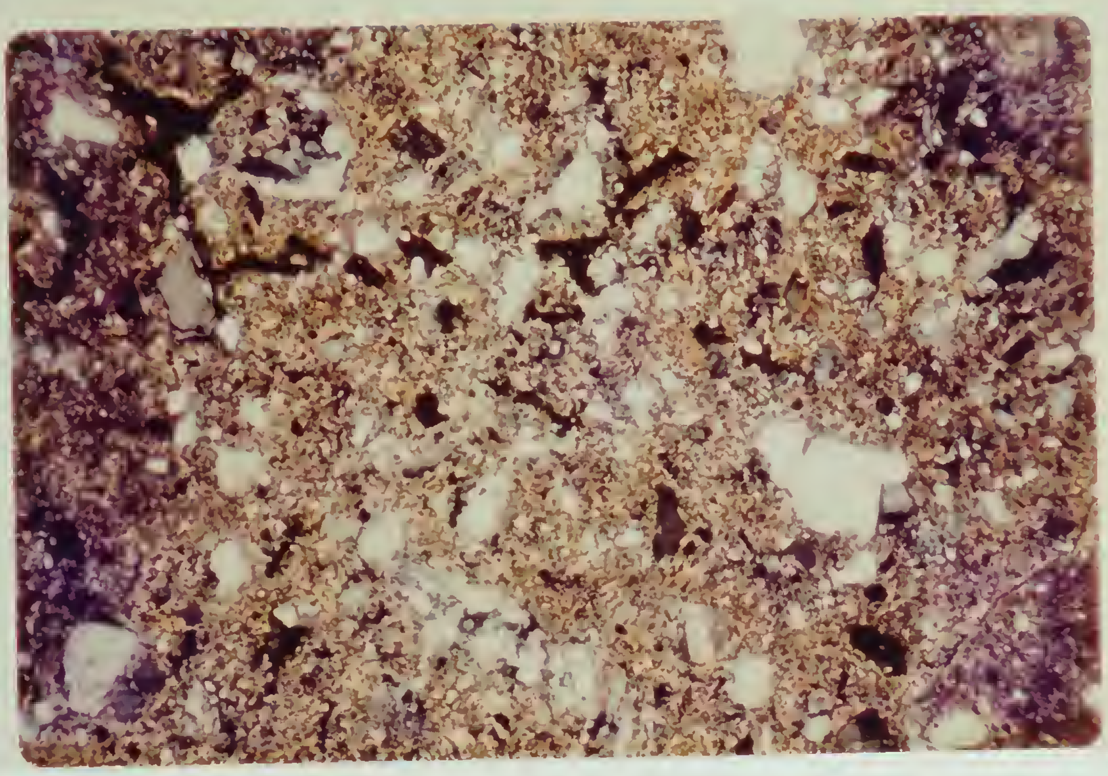


Plate 6.1 Photomicrograph of argillasepic plasmic fabric in lower portion of Bt_3 horizon of Pedon 5 at Site 3 (crossed polarizers).

poorly defined tertiary peds existed in the upper section of the Bt_3 horizon of this pedon.

Interpedal skew and craze planes were the predominant form of pore space by areal proportion in the upper and lower portions of the Bt_3 horizons in pedons 1 to 4 inclusive. In general, these planes were characterized by an increased length and greater linearity than similar planes in horizons of lesser depth. A large number of short, discontinuous, craze planes existed in association with secondary peds. Interconnected networks of planar voids were lesser in number due to the large size of peds. Intrapedal voids existed randomly in the s-matrix of the Bt_3 horizon with dimensions from 70 to 1400μ. The Bt_3 horizon of pedon 5 had an abundance of orthovughs and a lesser amount of planar voids than the other four pedons. This difference was most noticeable in the lower segment.

The distribution of skeleton in the Bt_3 horizon was unchanged from that reported for Bt_2 horizons. Argillans in the upper portion of the horizon in pedons 1 to 4 inclusive, ranged in thickness from less than 8 to 60μ and consisted of skew and craze plane argillans with strong, parallel orientation. These planar argillans associated with ped surfaces were discontinuous in all cases but possessed sharp boundaries and moderate separation when viewed at higher magnifications (120x). Metavugh argillans with strong and relatively continuous parallel orientation, sharp boundaries and fairly strong separation were also present. The upper portion of the Bt_3 horizon in pedon 5 had very few void argillans, those present were predominantly metavugh argillans.

The lower portion of the horizon had no void argillans at the magnification used (40x). Some sedimentary rock fragments had embedded grain cutans with poorly to moderately defined parallel orientation, weak boundaries and poor separation. Ungrouped plasma separations existed randomly in the s-matrix.

The plasmic fabric of the upper segment of the Bt_3 horizon was best defined as ma-vosepic and the lower portion as vo-masepic for pedons 1 to 4 inclusive. The plasmic fabric of the Bt_3 horizon in pedon 5 was argillasepic throughout. All Bt_3 horizons exhibited a random skeletal distribution.

Descriptive analysis of the fabrics of the Bt horizons in pedons at Site 3 suggests illuviation to be the dominant pedogenic process as observed at Site 2. Pedon horizonation as interpreted from micromorphological observation is in disagreement with macromorphological observations and laboratory analyses. The horizon classified as Bt_1, would by microscopic observation appear to be a transition horizon (BA). A similar observation was made by Heil and Buntley (1965) in Williams soil of South Dakota. Their observations of less clay on ped faces in Bt_1 horizons suggested that the ped faces were being stripped of clay by eluviation. The maximum clay accumulation occurred on ped faces in the Bt_2 horizon, similar to observations at Site 2. This feature has also been reported by Gillespie and Elrick (1968) and Buol and Hole (1961), who suggest colloidal clay suspensions are deposited wherever the percolating water is arrested from downward movement. Pedon 5, a pedon of the Bremay Series, had Bt horizons similar to the Hubalta pedons by macromorphological observations but were distinctly different when observed in thin section.

The process of illuviation would appear to be hindered in this pedon in comparison with the other four pedons at Site 3. In addition to illuviation, processes of shrink-swell and freeze-thaw which produce stresses are suggested for all five pedons of Site 3 by the plasma separations.

III. MODAL ANALYSIS

The technique of modal analysis (Chayes, 1956; Anderson and Binnie, 1961) was employed to quantitatively evaluate the distribution of soil constituents on a micromorphological basis, using categories outlined in the Materials and Methods section. Four hundred points per thin section were counted on each individual thin section chosen from the duplicates used for descriptive micromorphology. Means, standard deviations and coefficients of variation were calculated for the five pedons at each site on the basis of two thousand points. Results obtained in counting are contained in Appendix C, pages C2 to C7 inclusive, for each individual thin section. Means and standard deviations for the five pedons at each site are tabulated on a percentage basis in Tables 10, 11, and 12 for Bt horizons at Sites 1, 2, and 3, respectively. Means, standard deviations and coefficients of variation for total skeleton, total voids, total plasma and total cutans on a percentage basis are tabulated in Tables 13, 14, and 15 for Bt horizons in pedons at Sites 1, 2, and 3, respectively.

The skeletal fraction increased with depth varying from about 30 to 40 percent with a decreasing coefficient of variation in the Bt horizon in pedons at Site 1. Bt horizons in pedons at Site 2 had a fairly consistent skeletal content of about 30 percent from the upper portion of the Bt_1 to the lower portion of the Bt_2. The skeletal constituents in pedons at Site 3 varied from about 30 to 40 percent from the upper portion of the Bt_1 to the lower portion of the Bt_3, respectively with an increasing coefficient of variation with depth. The mineral

TABLE 10.

MEAN VALUES AND STANDARD DEVIATIONS OF MICROMORPHOLOGICAL CONSTITUENTS OF Bt HORIZONS FOR PEDONS AT SITE 1 ON A PERCENTAGE BASIS

Micromorphological Constituent	Horizon			
	Bt(u)*		Bt(l)**	
	% Mean	% Std. Dev.	% Mean	% Std. Dev.
Minerals	10.30	2.31	10.40	1.78
Rock Fragments	21.00	9.76	27.80	6.00
Orthovughs	0.80	0.67	0.75	0.64
Metavughs	9.20	5.62	6.45	4.66
Planes	4.90	3.84	4.90	2.82
Other Voids	3.55	2.94	4.00	3.31
Plasma Around Skeleton	13.60	3.04	15.15	2.82
Random Plasma	25.40	8.61	19.85	4.84
Other Plasma	6.55	2.16	5.25	1.02
Plane Cutans	1.20	1.05	1.55	0.45
Vugh Cutans	1.35	0.80	1.50	1.00
Other Cutans	1.50	0.85	2.25	0.59
Organic Matter	0.65	0.63	0.20	0.27

* u refers to upper portion of horizon

** l refers to lower portion of horizon

TABLE 11.

MEAN VALUES AND STANDARD DEVIATIONS OF MICROMORPHOLOGICAL CONSTITUENTS OF Bt HORIZONS FOR PEDONS AT SITE 2 ON A PERCENTAGE BASIS

Micromorphological Constituents	Horizon			
	Bt_1(u)		Bt_1(l)	
	% Mean	% Std. Dev.	% Mean	% Std. Dev.
Minerals	19.30	3.49	18.30	5.44
Rock Fragments	9.35	3.37	11.85	6.35
Orthovughs	0.45	0.37	0.05	0.11
Metavughs	3.00	1.57	2.40	2.00
Planes	4.65	2.11	3.00	1.08
Other Voids	5.25	2.46	6.30	1.82
Plasma Around Skeleton	17.85	1.50	19.75	2.43
Random Plasma	25.10	5.06	21.70	2.51
Other Plasma	12.45	2.22	11.10	3.05
Plane Cutans	1.60	1.67	2.70	3.12
Vugh Cutans	0.60	0.52	0.80	0.69
Other Cutans	0.35	0.42	0.55	0.60
Organic Matter	0.05	0.11	1.45	2.69

Horizon			
Bt_2(u)		Bt_2(1)	
% Mean	% Std. Dev.	% Mean	% Std. Dev.
16.40	3.99	20.35	4.01
12.75	4.77	11.30	4.08
0.15	0.22	1.00	1.69
1.60	0.84	2.15	0.45
5.50	2.40	3.40	2.66
4.05	1.55	4.95	2.65
19.70	3.26	20.25	2.48
22.30	2.64	17.60	5.77
12.55	1.86	14.80	4.81
2.95	1.51	1.30	0.76
1.25	1.02	1.20	1.10
0.45	0.37	0.65	0.58
0.35	0.34	1.05	0.97

TABLE 12.

MEAN VALUES AND STANDARD DEVIATIONS OF MICROMORPHOLOGICAL CONSTITUENTS OF Bt HORIZONS FOR PEDONS AT SITE 3 ON A PERCENTAGE BASIS

Micromorphological Constituents	Horizon			
	Bt_1(u)		Bt_1(1)	
	% Mean	% Std. Dev.	% Mean	% Std. Dev.
Minerals	15.50	2.42	18.40	1.69
Rock Fragments	15.80	2.69	15.10	3.10
Orthovughs	0.45	0.41	0.00	0.00
Metavughs	2.70	1.65	2.90	1.75
Planes	11.65	2.08	9.05	3.35
Other Voids	5.55	2.16	5.25	3.65
Plasma Around Skeleton	18.50	1.90	20.20	1.64
Random Plasma	12.80	3.19	12.55	1.04
Other Plasma	13.10	3.23	12.60	2.86
Plane Cutans	1.25	1.35	1.30	0.91
Vugh Cutans	0.70	0.62	1.45	1.36
Other Cutans	0.55	0.48	0.30	0.21
Organic Matter	1.45	0.86	1.00	0.68

Horizon							
Bt_2(u)		Bt_2(l)		Bt_3(u)		Bt_3(l)	
% Mean	% Std. Dev.	% Mean	% Std. Dev.	% Mean	% Std. Dev.	% Mean	% Std. Dev.
19.50	1.59	17.55	2.08	19.70	2.16	19.20	1.96
16.90	2.37	17.20	6.76	18.60	3.00	18.95	2.75
0.10	0.22	0.00	0.00	0.00	0.00	0.15	0.34
3.30	1.96	3.95	0.99	4.10	0.99	3.35	1.33
5.70	3.35	8.05	2.53	7.15	3.00	4.55	1.44
3.60	0.95	4.45	1.05	3.50	0.85	5.75	1.37
20.60	1.42	20.40	1.88	19.15	3.08	19.25	5.04
10.90	0.58	10.95	2.12	11.40	2.12	13.55	3.98
13.85	1.68	12.10	1.65	12.40	3.74	11.20	1.99
2.85	1.42	2.70	1.69	1.50	0.64	1.10	0.91
1.55	1.05	1.80	0.37	1.55	0.69	2.00	0.85
0.65	0.29	0.45	0.54	0.60	0.52	0.45	0.41
0.50	1.12	0.40	0.63	0.20	0.45	0.50	0.05

TABLE 13.

MEANS, STANDARD DEVIATIONS, AND COEFFICIENTS OF VARIATION FOR TOTAL SKELETON, TOTAL VOIDS, TOTAL PLASMA, AND TOTAL CUTANS FOR Bt HORIZONS AT SITE 1 ON A PERCENTAGE BASIS

Fabric Component	Horizon Bt(u)	Bt(l)
Total Skeleton (Mean)	31.30	38.15
Std. Dev.	8.89	4.93
C.V.	28.4	12.9
Total Voids (Mean)	18.45	16.10
Std. Dev.	6.55	4.44
C.V.	35.5	27.6
Total Plasma (Mean)	45.65	40.25
Std. Dev.	8.00	5.80
C.V.	17.6	14.4
Total Cutans (Mean)	4.05	5.30
Std. Dev.	2.17	1.08
C.V.	53.5	20.4

TABLE 14.

MEANS, STANDARD DEVIATIONS, AND COEFFICIENTS OF VARIATION FOR TOTAL SKELETON, TOTAL VOIDS, TOTAL PLASMA, AND TOTAL CUTANS FOR Bt HORIZONS AT SITE 2 ON A PERCENTAGE BASIS

Fabric Component	Horizon			
	Bt_1(u)	Bt_1(l)	Bt_2(u)	Bt_2(l)
Total Skeleton (Mean)	28.65	30.15	29.15	31.65
Std. Dev.	4.08	7.22	3.08	5.87
C.V.	14.3	23.9	10.5	18.5
Total Voids (Mean)	13.35	11.75	11.30	11.50
Std. Dev.	4.24	2.05	3.68	2.10
C.V.	31.8	17.4	32.6	18.3
Total Plasma (Mean)	55.40	52.55	54.55	52.65
Std. Dev.	6.71	4.63	5.75	6.53
C.V.	12.1	8.8	10.5	12.4
Total Cutans (Mean)	2.55	4.05	4.65	3.15
Std. Dev.	2.12	3.78	1.88	1.28
C.V.	83.0	93.4	40.5	40.7

TABLE 15.

MEANS, STANDARD DEVIATIONS, AND COEFFICIENTS OF VARIATION FOR TOTAL SKELETON, TOTAL VOIDS, TOTAL PLASMA, AND TOTAL CUTANS FOR Bt HORIZONS AT SITE 3 ON A PERCENTAGE BASIS

Fabric	Horizon					
Component	Bt_1(u)	Bt_1(1)	Bt_2(u)	Bt_2(1)	Bt_3(u)	Bt_3(1)
Total Skeleton (Mean)	31.30	33.50	36.40	34.75	38.40	38.15
Std. Dev.	1.14	1.91	1.18	7.15	3.70	2.56
C.V.	3.6	5.7	3.2	20.6	9.6	6.7
Total Voids (Mean)	20.35	17.20	12.70	16.45	14.75	13.80
Std. Dev.	3.71	5.17	2.79	3.51	3.99	1.93
C.V.	18.2	30.1	22.0	21.3	27.0	14.0
Total Plasma (Mean)	44.40	45.35	45.35	43.45	42.95	44.00
Std. Dev.	5.66	3.74	0.60	3.47	5.70	1.85
C.V.	12.8	8.2	1.3	8.0	13.3	4.2
Total Cutans (Mean)	2.50	3.05	5.05	4.95	3.65	3.55
Std. Dev.	1.59	1.95	1.87	2.37	1.17	1.67
C.V.	63.6	63.9	36.9	48.0	32.0	47.1

portion of the skeleton remained fairly constant at about 10, 20, and 20 percent for Bt horizons in pedons at Sites 1, 2, and 3, respectively with the least standard deviation at Sites 1 and 3. A discrepancy is noted however in the upper portion of Bt_1 horizons at Site 3 where a lesser value of about 15 percent was measured. Rock fragment values show a general increase with depth in the pedons at all three sites as shown in Tables 10, 11, and 12. This trend is in agreement with the observed trends reported in the Descriptive Micromorphology section and offers additional support to proposed processes of weathering.

The measurable pore space varied from about 18 percent in the upper portion of the Bt with a coefficient of variation of 36 percent to about 16 percent in the lower portion of the Bt with a coefficient of variation of 28 percent at Site 1. Orthovughs were consistently less than 1 percent in both sections of the horizons with large standard deviations relative to the mean and metavughs decreased slightly from about 9 to 6 percent with increasing depth with large standard deviations relative to the mean. The areal proportion occupied by planes in thin section was consistently about 5 percent of the total with decreasing standard deviations with increasing depth. Other forms of voids accounted for about 4 percent of the soil sample in thin section with standard deviations near 3 percent.

Pedons at Site 2 had a total pore space of about 14 percent and a coefficient of variation of 32 percent in the upper portion of the Bt_1 horizon and a mean of about 12 percent with a coefficient of variation of 17 percent in the lower portion of the Bt_1. The pore space of the Bt_2 horizons was consistent at about 12 percent with a

decreasing standard deviation with increasing depth. Orthovughs again represented a very small proportion of the thin section, being from 0 to 0.5 percent until the lower portion of the Bt_2 horizon where an increase to about 1 percent was measured. Standard deviations for orthovughs are in most cases larger than the mean. The proportion of metavughs was fairly consistent among pedons at Site 2, varying from about 3 percent in the upper Bt_1 to about 2 percent in the lower Bt_2 with a decreasing coefficient of variation with increasing depth. Planes represented about 3 to 5 percent of the horizons with the variability not representative of any trend. The remainder of the pore space varied from about 4 to 6 percent with the largest values in the Bt_1 horizon and standard deviations ranging from 1.55 to 2.65

Pedons at Site 3 had a total pore space which varied from about 21 percent in the upper Bt_1 horizon to about 14 percent in the lower portion of the Bt_3 with the largest coefficient of variation of 30 percent in the lower portion of the Bt_1. The observed trend of larger amounts of pore space in the Bt_1 and lesser amounts with increasing depth is in accord with bulk density measurements and trends observed in the Descriptive Micromorphology section. Orthovughs again represent a small (0 to 0.5 percent) proportion of these Bt horizons and show large coefficients of variation. Metavughs varied from about 3 percent in the Bt_1 to 3 to 4 percent in the Bt_2 and Bt_3 with standard deviations variable from 1.65 to 4.10, respectively. Planes constituted about 12 and 9 percent of the upper and lower segments of the Bt_1 with standard deviations of 2.08 and 3.35, respectively. The proportion of planes decreased from about 8 to 5 percent with a fluctuating coefficient of variation with increasing

depth in the pedon. This trend is in agreement with observations in the Descriptive Micromorphology section. Other forms of pore space in the pedons constituted about 5 to 6 percent of the Bt_1 with decreasing abundance to about 3 to 4 percent and an increase to about 6 percent in the lower segment of the Bt_3 horizon.

Total plasma constituted about 50 and 45 percent of the upper and lower portions of the Bt horizons at Site 1, with coefficients of variation of 32 and 23 percent, respectively. It is suggested that this difference may be explained, in part, by the weathering of sedimentary rocks as suggested previously or by the occurrence of loess. About 14 to 15 percent of the plasma with standard deviations of 3.04 and 2.82 in the upper and lower segments, respectively, was directly associated with skeleton grains in the manner outlined in the Materials and Methods section. Random plasma varied in the opposite manner with about 25 and 20 percent in the upper and lower portions, respectively. Cutans represented about 4 percent of the upper portion, with a coefficient of variation of 54 percent and about 5 percent of the lower portion with a coefficient of variation of 20 percent. Of the cutans, plane argillans represented about 1 to 1.5 percent of the horizon and vugh argillans about 1.5 percent. Plane argillans showed large standard deviations of 1.05 and 0.45, respectively, for the upper and lower segments. The increase from 1.5 to 2.3 percent, tabulated as "other cutans" with relatively low standard deviations of 0.85 and 0.59, respectively, represents the increasing proportion of skeletal argillans abundant in these horizons.

Total plasma constituted about 56 to 59 percent of the Bt

horizons in pedons at Site 2 and was consistent in this range as depth increased, and had coefficients of variation varying from 9 to 12 percent. About 18 to 20 percent of the plasmic materials were directly associated with skeleton grains, with standard deviations ranging from 1.50 to 3.26. Approximately 18 percent of the plasma with a standard deviation of 5.77 in the lower segment of the Bt_2, to 25 percent with a standard deviation of 5.06 in the upper segment of the Bt_1 was randomly distributed in the pedon. The increasing means (about 11 to 15 percent) for "other plasma" as reported in Table 11 is related, in this case, to the increasing occurrence of plasma separations as reported in the Descriptive Micromorphology section. Cutans represented about 3 percent of the upper Bt_1 horizon with a coefficient of variation of 83 percent, increased to about 5 percent in the upper Bt_2 with a coefficient of variation of 41 percent, and decreased to about 3 percent, with a coefficient of variation of 41 percent in the lower portion of the Bt_2. This trend supports the suggestion of the pedogenic process of illuviation. Plane argillans were the cutanic feature of highest frequency and varied from about 2 to 3 percent in the upper and lower Bt_1, respectively, with large standard deviations. Vugh cutans were less than 1 percent of the Bt_1 horizon and about 1 to 1.3 percent of the Bt_2 horizon with large standard deviations ranging from 0.52 to 1.10. Other forms of cutanic features were less than 1 percent of either horizon with relatively large standard deviations which supported the observed tendency to very few skeletal cutans in these pedons.

Bt horizons in pedons at Site 3 consisted of about 47 to 51 percent plasmic materials with little variation as increasing depth.

As was the case in pedons at Site 2 about 18 percent with a standard deviation of 1.90, to about 20 percent with a standard deviation of 1.88 of the plasma was directly associated with skeleton grains. About 10 to 14 percent of the Bt horizons was randomly distributed plasma, with standard deviations ranging from 0.58 to 3.98, representing a decrease of from 8 to 10 percent when compared to Site 2. Materials categorized as other plasma represented about 11 to 14 percent of the Bt horizons. Cutans in these pedons represented about 3 percent of both segments of the Bt_1 horizon with coefficients of variation equal to 64 percent. As was observed in the Descriptive Micromorphology section, the proportion of cutans maximized at about 5 percent in the Bt_2 horizon with a coefficient of variation of 37 percent and decreased to less than 4 percent in the Bt_3 horizon with a coefficient of variation of 47 percent, in keeping with the proposed processes of pedogenesis. Plane argillans made up about 1.5 percent of the Bt_1 horizon and about 3 percent of the Bt_2 horizon, with respective standard deviations of 1.35 and 1.42. The occurrence of plane argillans decreased to about 1 to 1.5 percent in the Bt_3 horizon. Vugh argillans represented less than 1 percent of the upper Bt_1 horizon but increased with depth to a value of about 2 percent for the lower portion of the Bt_3, with relatively large coefficients of variation. As was the case in pedons examined at Site 2, the proportion of other cutanic features was less than 1 percent consistently, supporting the observation of few skeletal cutans in these pedons.

Organic matter represented a very small proportion of all Bt horizons investigated. The amount of organic matter varied randomly from 0 to 1.5 percent with respect to differences within replicate thin sections, Bt horizon, pedon and between the three sites.

IV. SCANNING ELECTRON MICROSCOPY

Studies of soil fabric are most useful in attaining information concerning properties of pedological features and interpretation of processes involved in their formation. Studies in fabric are dependent upon recognition and measurement of the arrangement in space of the constituents which make up the whole. Due to the low depth of field of optical microscopy, studies in soil fabric have previously been limited to thin section techniques regarding a planar surface. Clay minerals as defined (Soil Science Society of America, 1970), are less than 2μ in equivalent spherical diameter which is on the limit of the resolving power of an optical microscope with the objective lens under oil immersion. In addition to limited resolution, the small depth of focus of the optical microscope is reduced as magnification is increased. Study of soil fabric in the unaltered state is restricted by such optical limitations. Optical limitations may be overcome however, by the use of electron optical systems (Gillott, 1969).

Scanning electron microscopy is most useful in fabric studies (Gillott, 1970; Cescas et al., 1970; Lynn and Grossman, 1970) because of its high resolution and depth of focus. The very high resolution of transmission electron microscopy is not applicable to fabric studies due to the necessity of specimens thin enough to allow the complete penetration of the electron beam. Low resolution and low depth of focus of optical microscopy are insufficient for fabric analysis of unimpregnated fragments of soil peds.

The limits of magnification on the scanning electron microscope

are 20x and 50,000x which corresponds to scanning areas of 5 mm and 2μ square on the specimen, respectively. Image magnification is adjusted very rapidly as it is dependent on the length of the individual scanning movements which are readily altered. By this means an individual sample may be examined over a large number of surfaces at a wide range of magnifications in a relatively short period of time.

Since the image produced is a result of secondary electrons the most important cause of contrast in the image is the topography of the surface as a topographic high offers the largest surface area on a planar base. Very good contrast is obtained on surfaces such as soil peds due to the presence of "jagged" surfaces.

Maximum resolution attainable with the instrument is established at 150Å under optimum conditions and is always better than 300Å. The depth of field in the scanning electron microscope is at least 300 times greater than that of a light microscope at the same magnification when both types of microscope are adjusted for optimum performance. Due to the reflection geometry involved in the operation of the scanning electron microscope the surface is examined directly. The large depth of focus of the electron optical system may therefore be completely exploited.

The following are a series of scanning electron micrographs taken of surfaces of selected peds from Bt horizons in pedons at the three sampling sites. Photomicrographs presented are those representative of micropedological features in undisturbed structural units and are intended to exemplify observations made in the micromorphology section.

Plates 7.1 and 7.2 represent two photomicrographs taken on a natural ped surface from the Bt horizon in pedon 4 at Site 1 at 650x and 2.6K respectively. Plate 7.2 represents the center section of Plate 7.1. The lack of cutanic surfaces previously observed on faces of peds is well expressed by the random nature of the plasmic materials observable in these plates. At higher magnification (Plate 7.2) lack of orientation patterns in clay size particles is apparent. Some plate-like individual structures are observable on the right hand side of the photograph.

Plate 8.1 (at 2.4K) is a photomicrograph of surface material at the edge of a crack in the ped (possibly caused by drying). The upper right corner is representative of the ped surface in which the crack appears. To the left of this and lower is the wall of the crack with increasing depth. The photograph tends to show a relatively scattered assemblage of platelets with a series of stacking arrangements parallel to the upper surface of the ped. Interpretation of the photograph would suggest that perhaps an oriented surface coating existed, which by some force was pulled apart resulting in the exposed oriented plates.

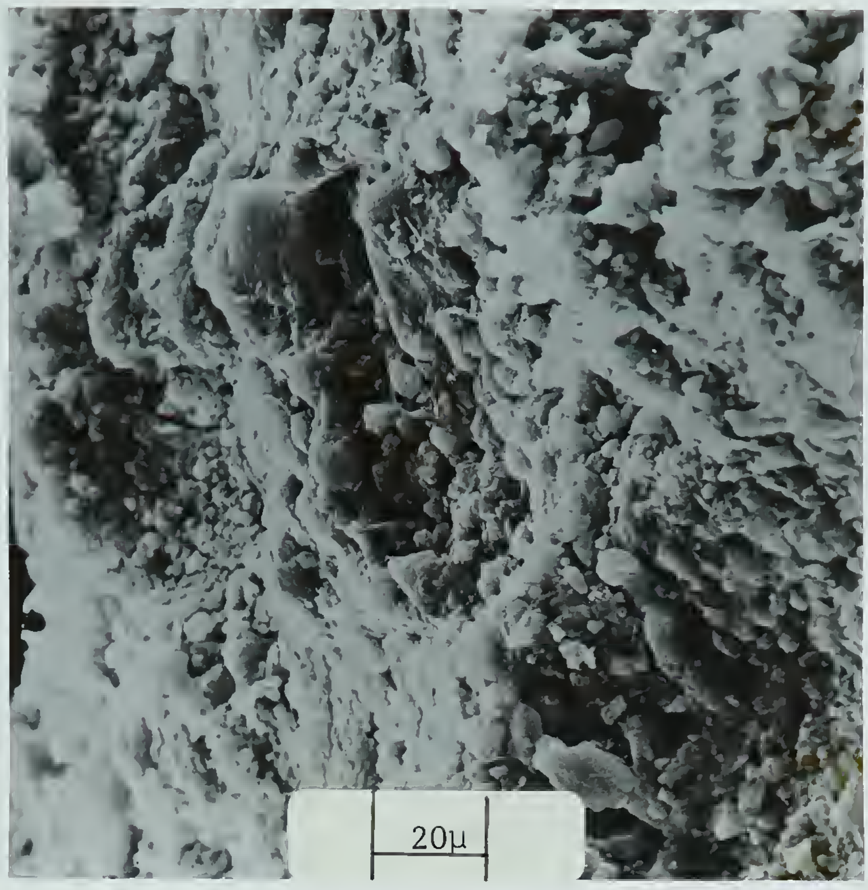


Plate 7.1 Natural ped surface. Magnification 650x.
(Site 1, Pedon 4, Bt Horizon).

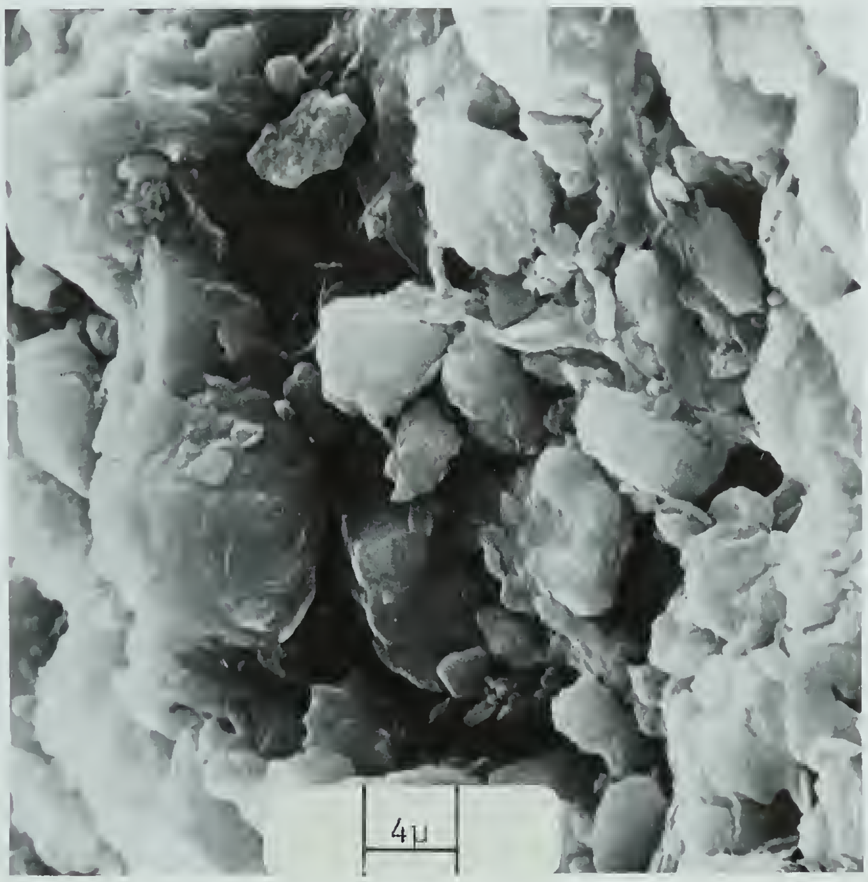


Plate 7.2 Central section of Plate 7.1 (natural ped surface)
Magnification 2.6K. (Site 1, Pedon 4, Bt Horizon).

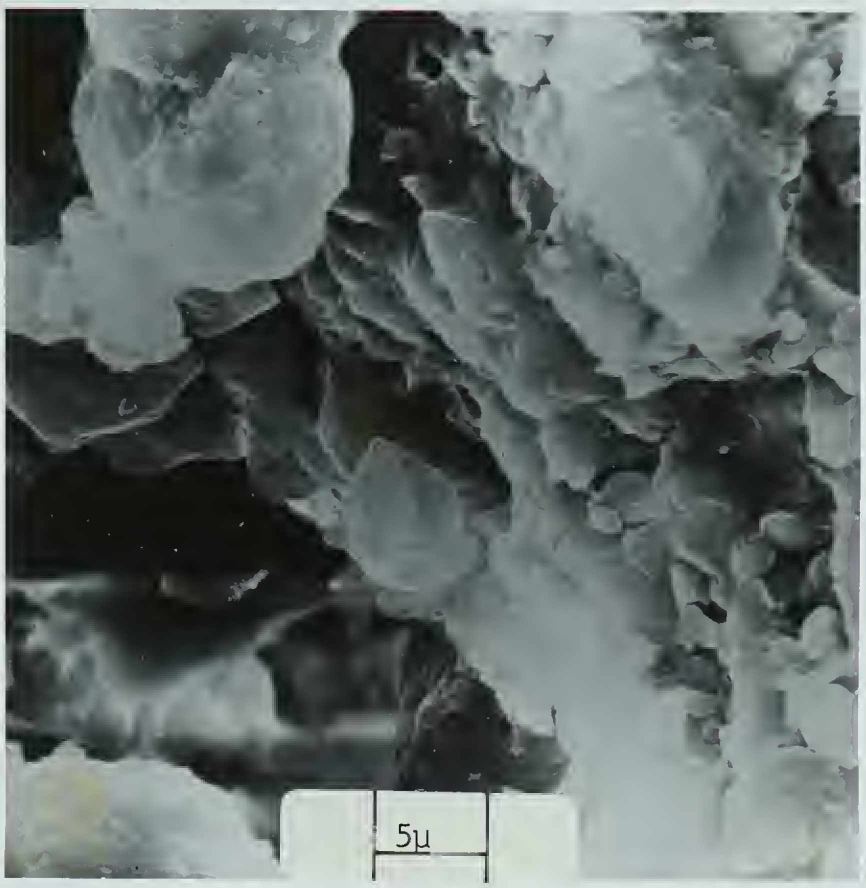


Plate 8.1 Surface material at edge of crack in ped.
Magnification 2.4K. (Site 1, Pedon 4, Bt Horizon).

The fabric of Bt horizons, as reported in the micromorphology section was in most cases dominantly skelsepic. Plates 9.1 and 9.2 (magnification 700x and 2.8K, respectively) represent an exposed skeleton grain with a cutanic surface. Plate 9.1 represents a corner of a sand grain extending out of the plasma of a ped from Site 1. Left and above center on the photographs the cutanic surface on the skeleton appears uplifted and broken. Plate 9.2 is a higher magnification of the tunnel-like feature clearly showing the skelsepic fabric orientation. The fabric boundaries are not as smooth and distinct as would be anticipated from their observation in thin sections. Some indentations on the surface of the skeleton grain are observable as well as a tendency to a hexagonal platy structure of some of the smaller plasmic substances.

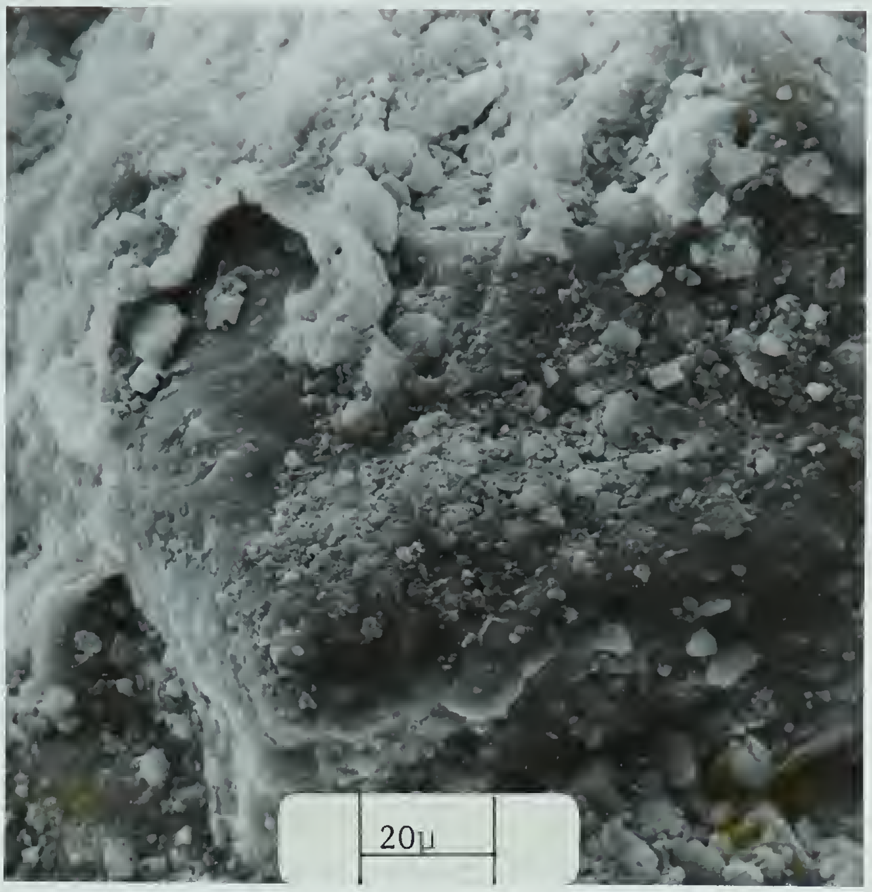


Plate 9.1 Coated skeleton grain with uplifted skeletal cutan. Magnification 700x. (Site 1, Pedon 4, Bt Horizon).

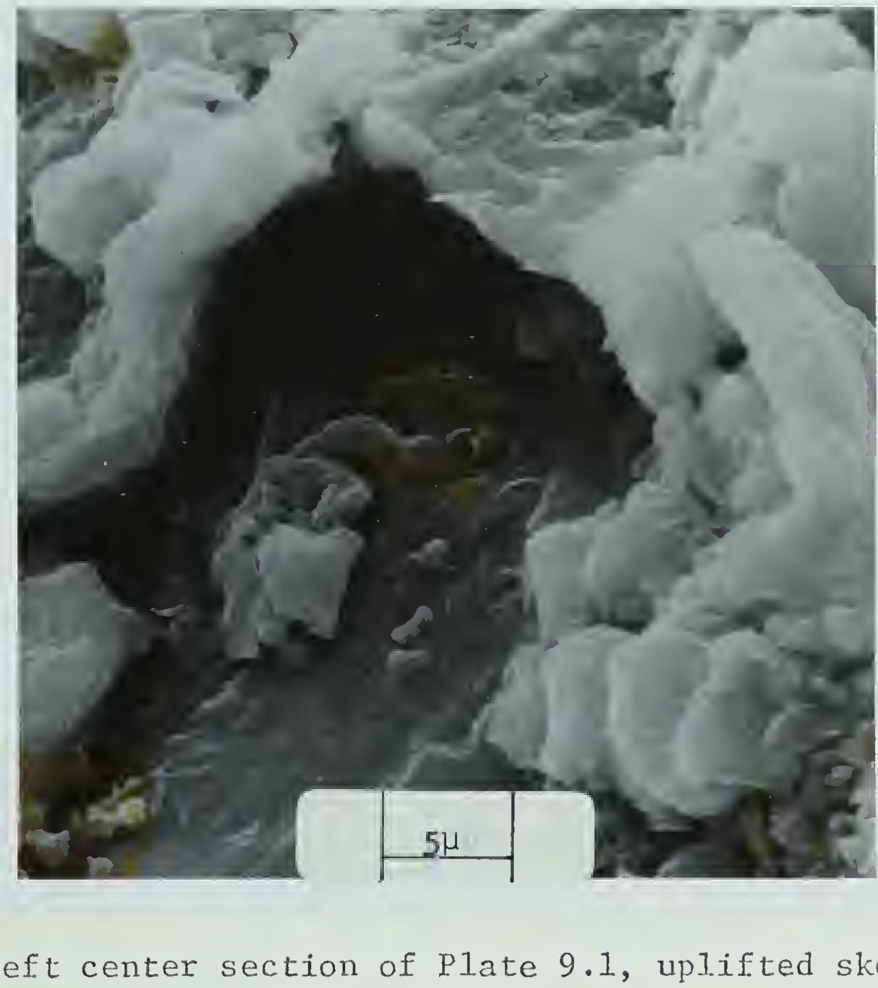


Plate 9.2 Left center section of Plate 9.1, uplifted skeletal cutan. Magnification 2.8K. (Site 1, Pedon 4, Bt Horizon).

Plate 10.1 at 135x magnification displays a portion of a root which penetrates a ped surface and extends into the interior. The ped surface surrounding the pore appears to be oriented to some degree as evidenced by striated lines with some parallel orientation. Plate 10.2 represents the central section of the previous photograph at a magnification of 1.35K directly at the edge of the root hole from an angle more parallel to the root fragments than Plate 10.1. The lower right portion shows a smooth planar surface in which clay platelets are readily observable. In the upper portion randomly distributed plasmic substances predominate probably caused by the action of the root. Considerable linear orientation is present on a small scale to the right of center.

The surface which is represented in Plates 11.1 and 11.2 (magnification 130x and 6.5K, respectively) was a plane within the ped caused to shear by a complex of observed roots. The roots had developed on a near planar path in a grid-like manner weakening the ped. Plate 11.1 shows the inped fabric matrix with abundant skeletal coatings and random plasma. Plate 11.2 accentuates the random nature of the fabric on the induced failure plane. Some structures of individual plasmic materials are observable with pseudo-hexagonal shape in addition to aggregates of oriented plasma.

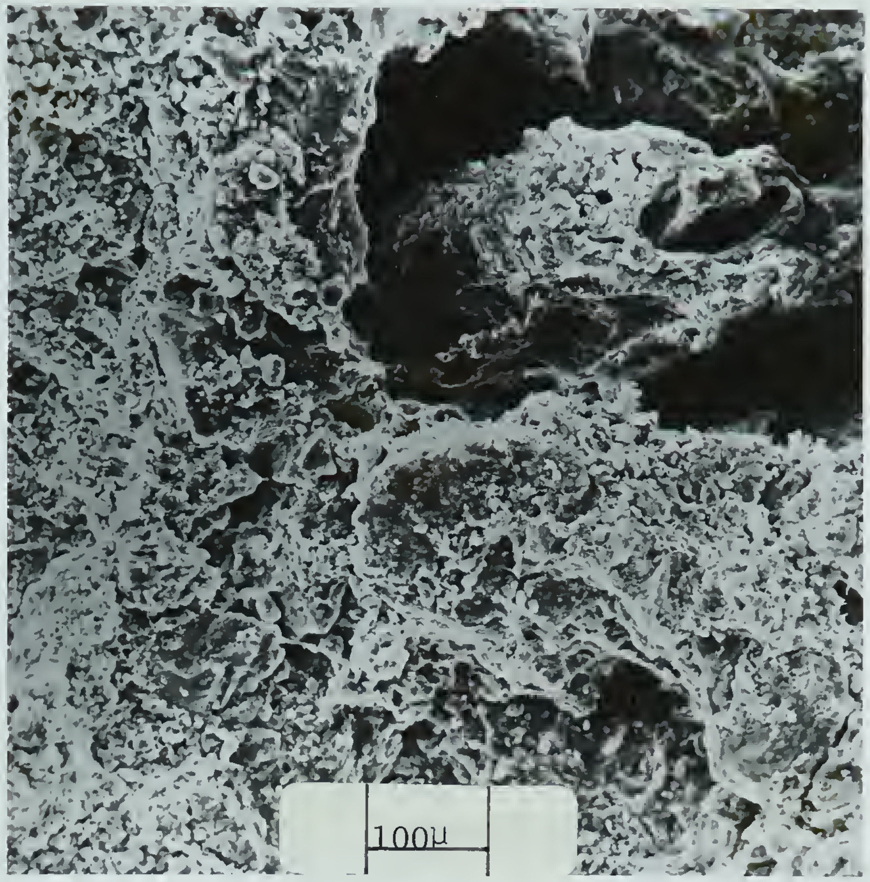


Plate 10.1 Portion of a root penetrating ped surface and extending to the interior. Magnification 135x. (Site 1, Pedon 4, Bt Horizon).

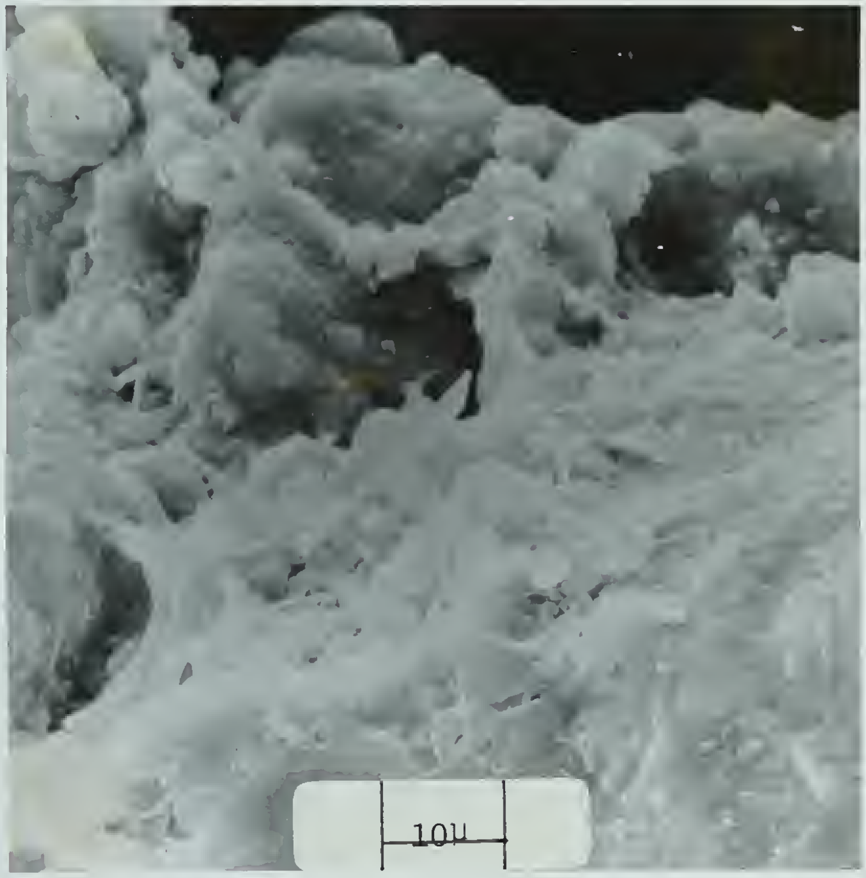


Plate 10.2 Edge of root hole in Plate 10.1 with smooth planar surface (lower right) and random distribution of plasma. Magnification 1.35K. (Site 1, Pedon 4, Bt Horizon).

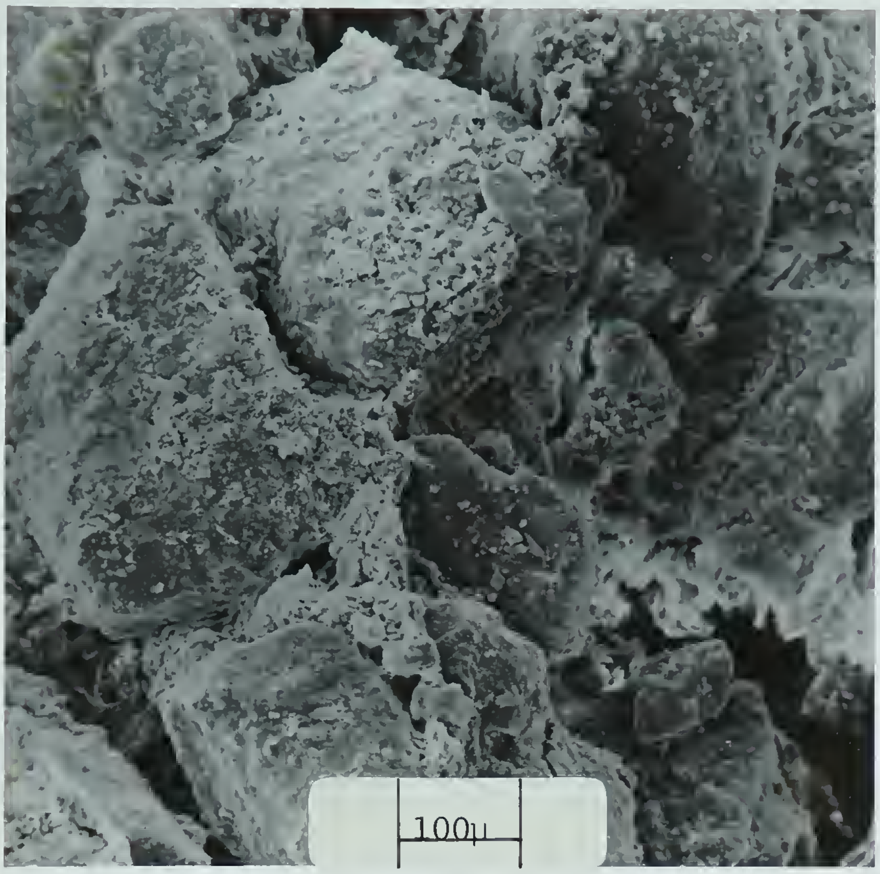


Plate 11.1 Failure plane in ped caused by root complex. Magnification 130x. (Site 1, Pedon 4, Bt Horizon).

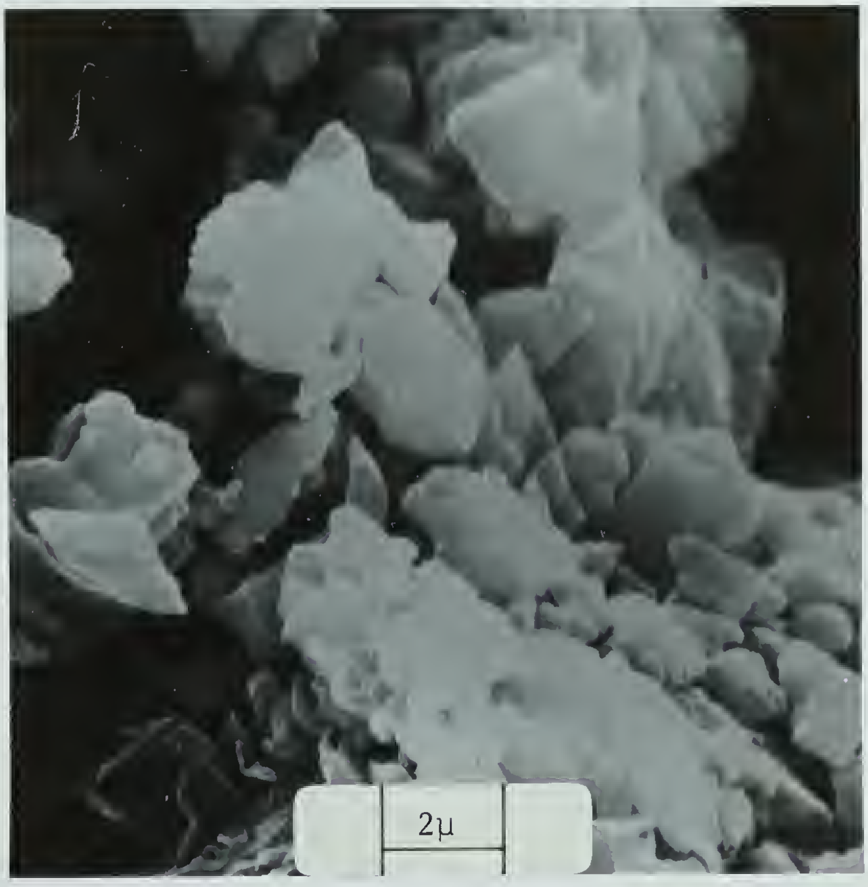


Plate 11.2 Section of Plate 11.1 showing arrangement of plasma on failure plane. Magnification 6.5K. (Site 1, Pedon 4, Bt Horizon).

Selected peds from Bt horizons of pedons at Site 2 revealed a different surficial fabric than peds from Site 1, which is in agreement with observations reported in the micromorphology section. Plate 12.1 taken at 280x magnification is a general view of a tubular pore into a ped through a plane cutan. Materials at the edge of the pore wall appear to be oriented parallel to the pore wall. Plate 12.2 taken at 1.4K illustrates the area at the edge of the pore in the upper right section of Plate 12.1. Orientation of materials and the stratified nature of the plane cutanic surfaces are readily observable. Structural units of individual clay size particles are not observed in this plate, perhaps due to relatively dense packing of the surficial material or lack of resolution in the photomicrograph.

Plate 13.1 represents a wall of the tubular pore in Plate 12.1. This photograph was taken at a magnification of 2.8K from an angle nearly parallel to the pore wall. The relatively smooth undisturbed nature of the pore wall and faint lines parallel to the surface above the pore may be attributed to the relatively thick continuous vugh cutans which had been observed in thin sections in Bt_1 horizons at Site 2. This photomicrograph suggests parallel orientation with the C-axis perpendicular to the wall.

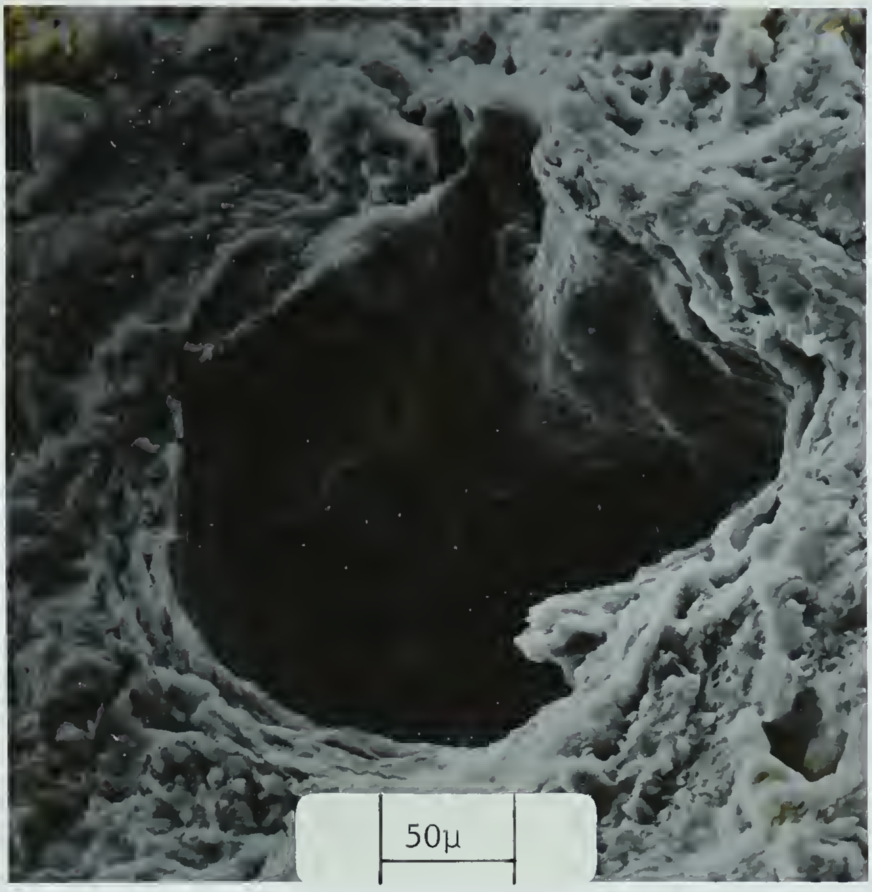


Plate 12.1 Tubular pore in ped. Magnification 280x. (Site 2, Pedon 5, Bt_1 Horizon).

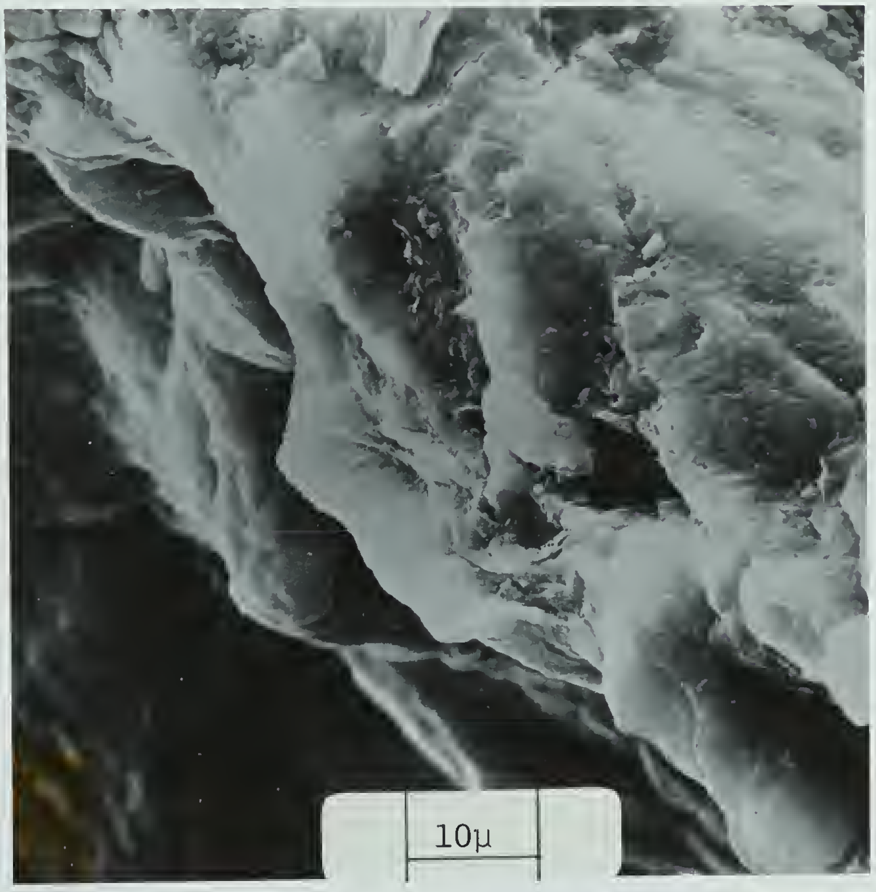


Plate 12.2 Edge of tubular pore in upper right of Plate 12.1. Magnification 1.4K. (Site 2, Pedon 5, Bt_1 Horizon).

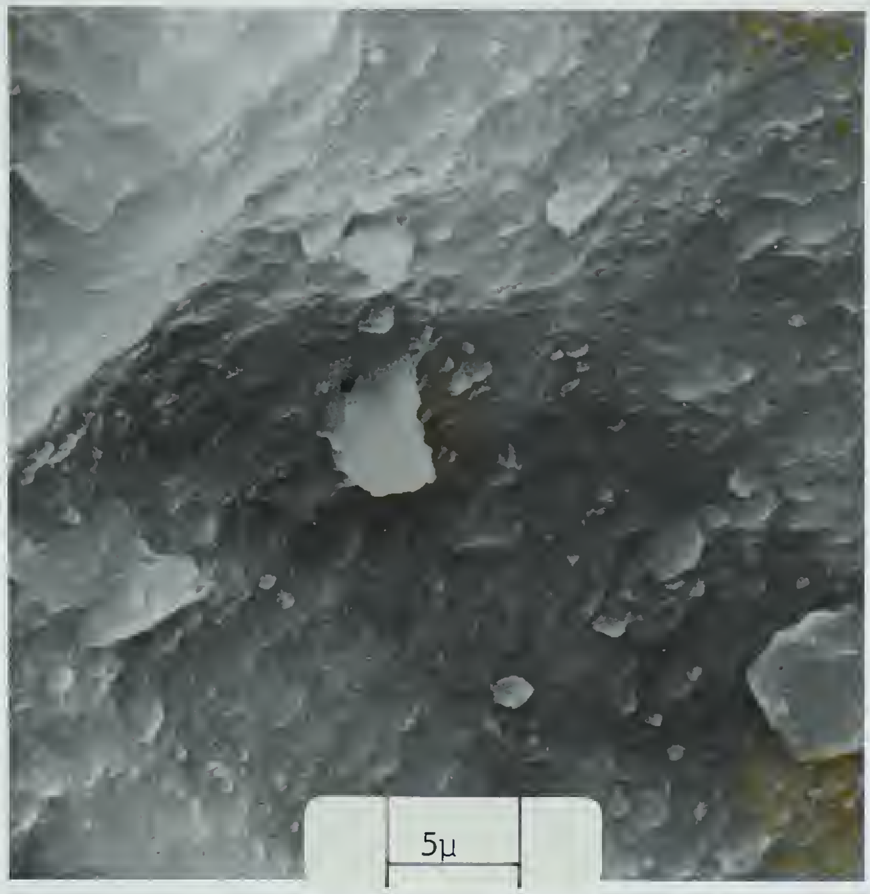


Plate 13.1 Wall of tubular pore in Plate 12.1. Magnification 2.8K. (Site 2, Pedon 5, Bt_1 Horizon).

Plate 14.1 is a photomicrograph of a cleavage surface on a ped from a Bt horizon at Site 2 at 67x. The lower right section of the photograph represents a root with a smaller protruding broken root extending toward the center. The plane on which the picture was taken represents a natural cleavage of the ped and appears smooth with some cracking perpendicular to the plane. The root channel continues for some distance (approximately 10 times that observed in photograph).

Plate 14.2 is a larger magnification (270x) of the central area of Plate 14.1. The light object in the lower right is the broken end of the root and appears to be coated with clays. To the left the oriented nature of the root channel walls and the random nature of much of the plasmic materials in the s-matrix possibly caused by root action may be observed.

Plate 15.1 taken at 6.7K in the center of Plate 14.2 is representative of the degree of orientation of clay plates along the root channel. Individual particle structures are observed as well as some degree of parallel stacking of the individuals.

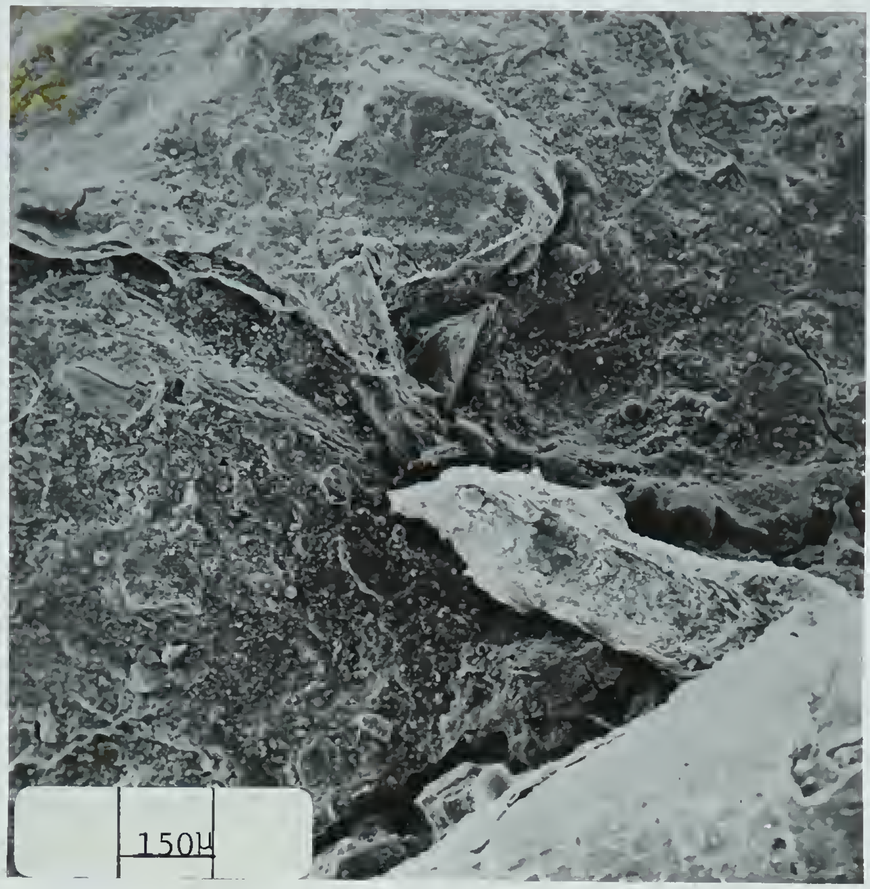


Plate 14.1 Failure plane in ped caused by root penetration. Magnification 67x. (Site 2, Pedon 5, Bt_1 Horizon).

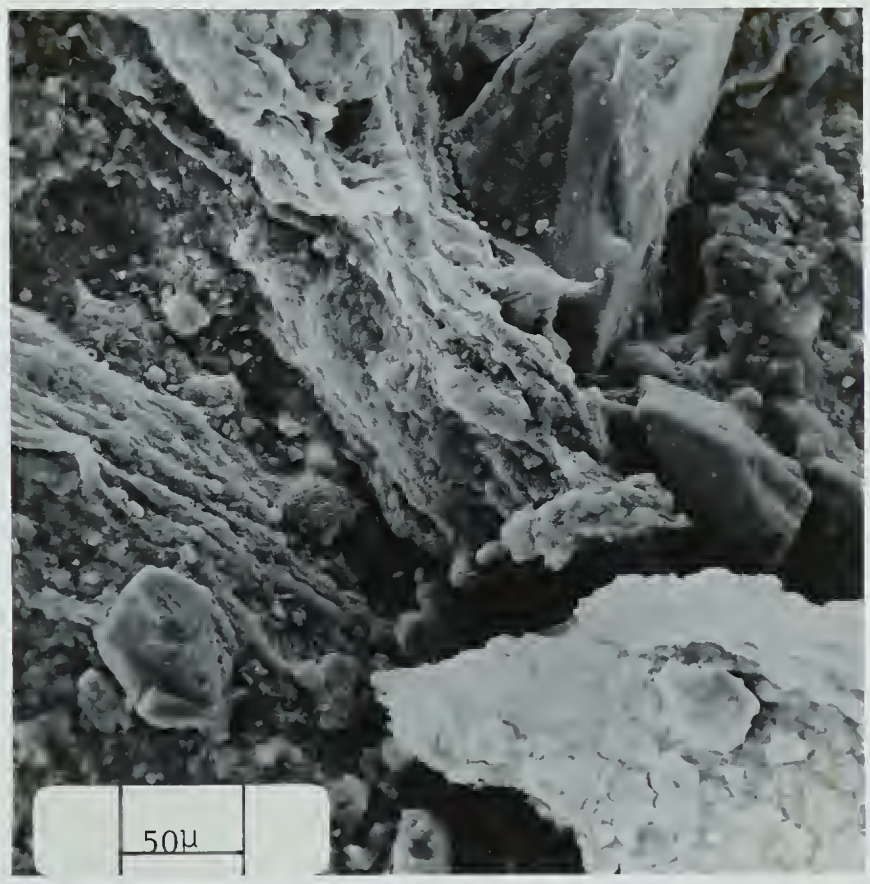


Plate 14.2 Central section of Plate 14.1. Root fragment in lower right. Magnification 270x. (Site 2, Pedon 5, Bt_1 Horizon.

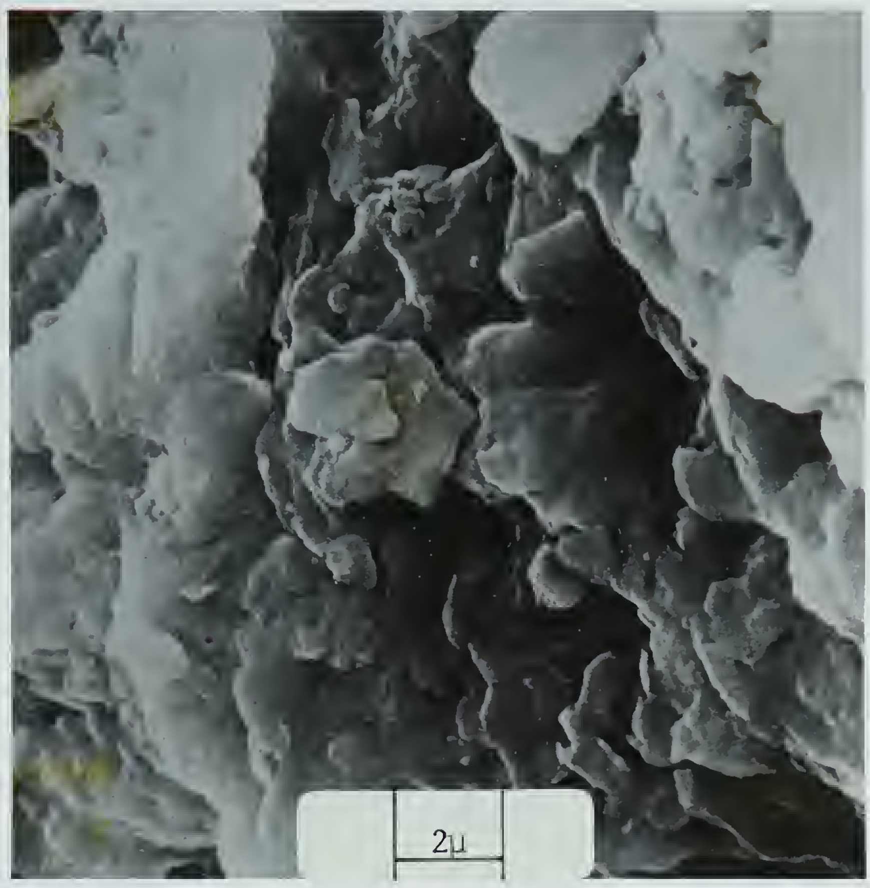


Plate 15.1 Center section of Plate 14.2 showing oriented clays in root channel. Magnification 6.7K. (Site 1, Pedon 5, Bt_1 Horizon).

Plates 16.1 and 16.2 represent a photomicrograph of a planar crack perpendicular to a cutanic surface on a ped from the Bt_1 horizon of pedon 5 at Site 2. Plate 16.1 (620x) is a general view of the crack normal to the ped surface. The upper portion of the photograph is of the cutanic surface of the ped. The object in the left portion of the photograph appears to be a root pulled out by forces causing the formation of the crack. The most probable cause of the crack is from drying of the specimen. Plate 16.2 was taken at 12.5K directly at the top of the crack where it penetrates the cutanic surface of the ped. The lines of orientation observed in the photograph are parallel to the upper planar surface. Clay size particle structures at this high magnification are not yet readily observable. This could be due to the well oriented parallel stacking in this argillan or the predominance of very fine clay size particles.

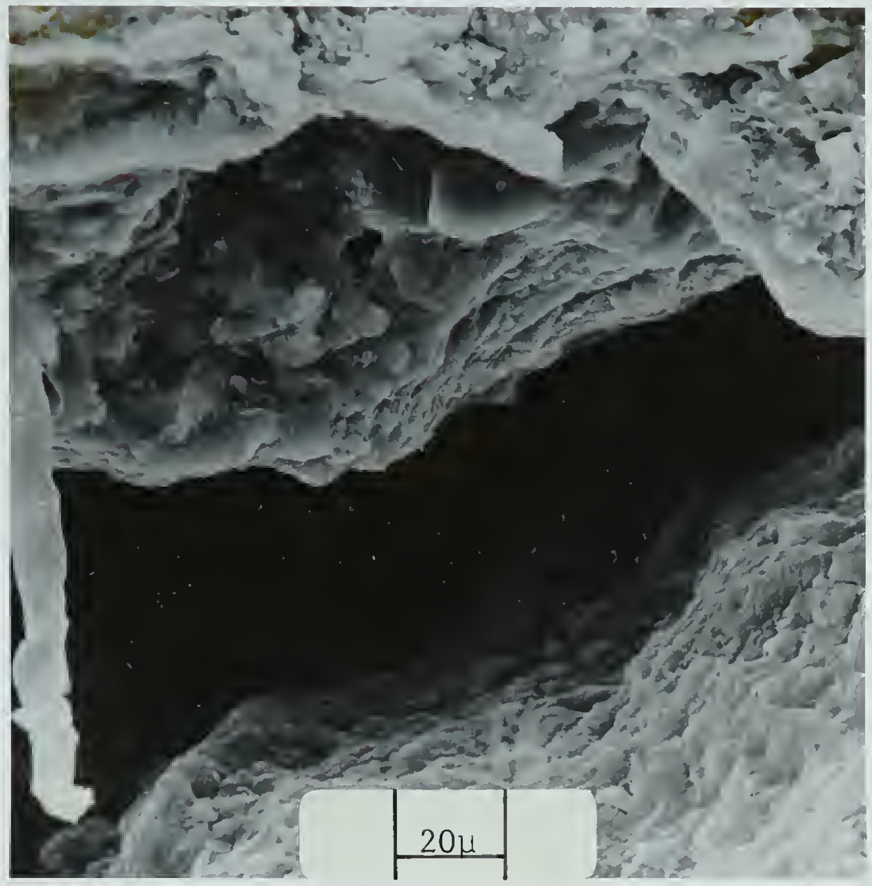


Plate 16.1 Planar crack normal to cutanic surface on ped. Magnification 620x. (Site 2, Pedon 5, Bt_1 Horizon).

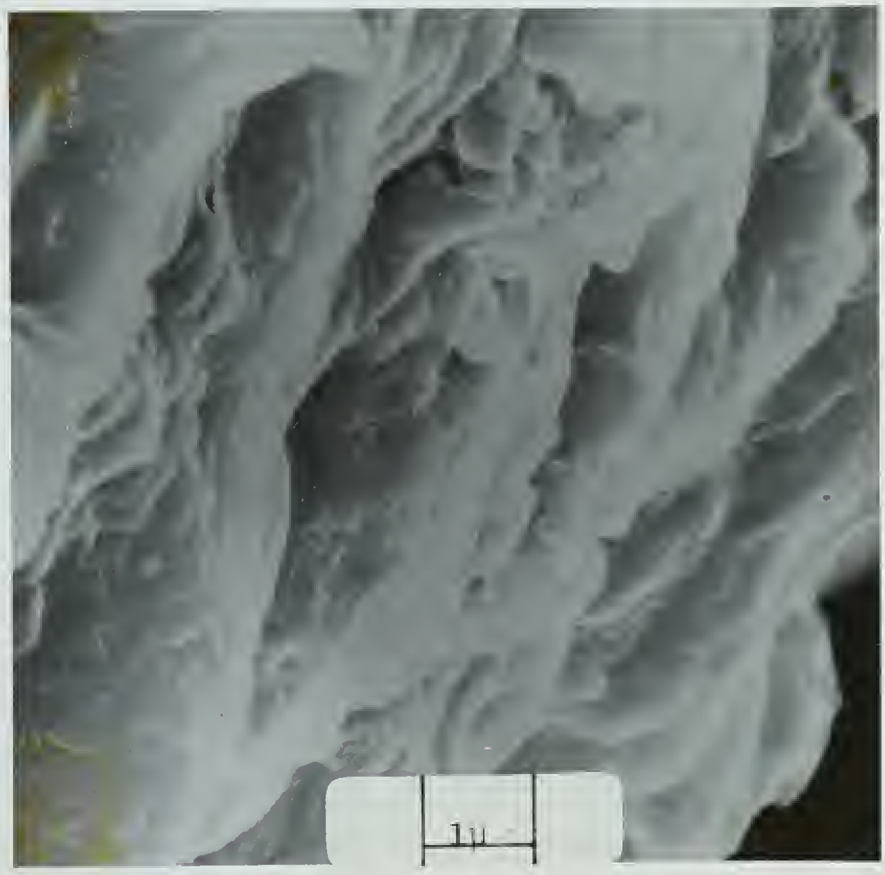


Plate 16.2 Edge of crack in Plate 16.1 at upper surface. Magnification 12.5K. (Site 2, Pedon 5, Bt_1 Horizon).

Interpedal argillans were described in the micromorphology section as skew plane argillans which had a strong and continuous, parallel orientation, characterized by a sharp boundary and strong separation, for Bt horizons of pedons from Site 2. Plates 17.1 and 17.2 represent scanning electron micrographs of such an argillan from an angle approximately 30° from the normal of the skew plane. Plate 17.1 at 1.4K magnification shows the relatively smooth surface, parallel orientation and continuity of these argillans. Individual plate-like structures are observable in this photograph but are accentuated in Plate 17.2 at 7K magnification, taken near the center of the previous plate at a slight angle from the normal to the plane in an attempt to express the face to face stacking array.

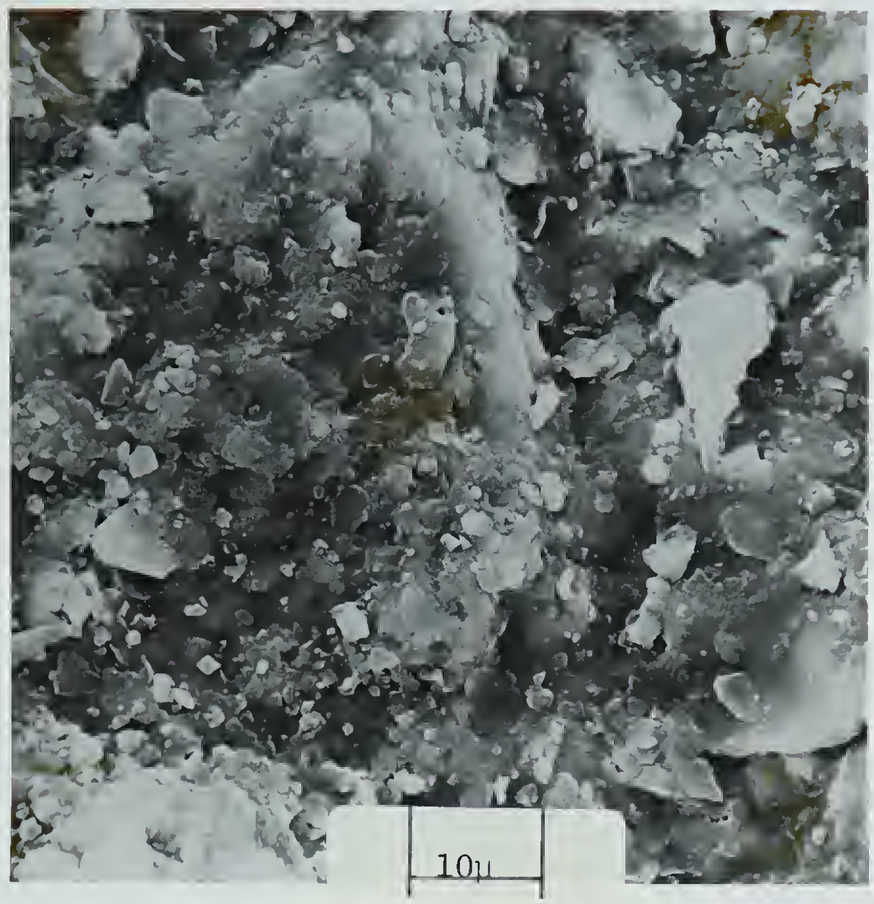


Plate 17.1 Skew plane argillan on ped (photographed normal to surface). Magnification 1.4K. (Site 2, Pedon 5, Bt_1 Horizon).

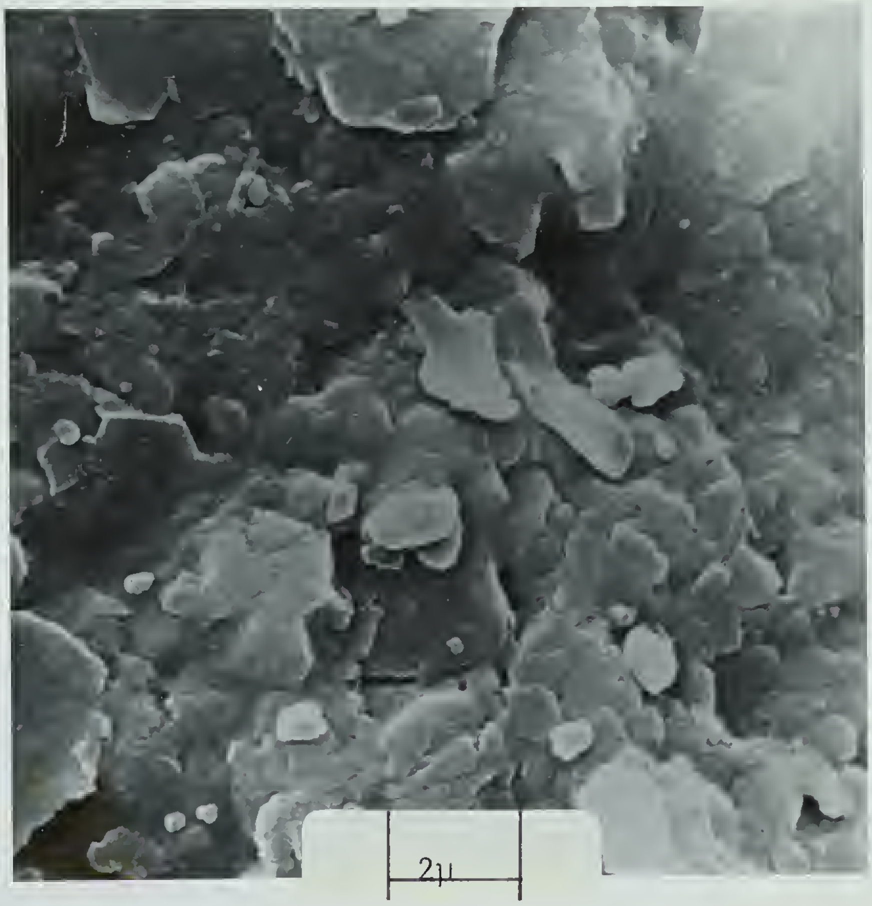


Plate 17.2 Central section of Plate 17.1. (Photographed at an angle approximately 30° from the normal). Magnification 7K. (Site 2, Pedon 5, Bt_1 Horizon).

In addition to plane argillans, slickensides were reported in the Bt horizons of the pedons at Site 2. Plate 18.1 taken at 2.7K at an angle of approximately 45° from the argillan plane represents the general appearance of slickensides as observed with scanning electron microscopy. The smooth surface appears in the photograph to be amorphous or highly polished. This micrograph allows no interpretation of orientation or individual clay structures. Photographs at a higher magnification were not possible due to the topographic nature of the surface which resulted in specimen charging.

Plate 18.2 at 2.4K was recorded at the edge of the feature in Plate 18.1. The horizontal center line of the photograph is representative of the broken slickenside from an edge view. Areas above and below the center represent the slickenside surface and s-matrix plasmic material, respectively. The most noticeable feature of this plate is the clear, wave-like line corresponding to an edge view of the plates forming the slickenside. Individual structures are again not observable in the slickenside but are noticeable in the plasmic material within the ped.

Plate 18.1 Slickenside on ped (photographed 45° from normal). Magnification 2.7K. (Site 2, Pedon 5, Bt_2 Horizon).

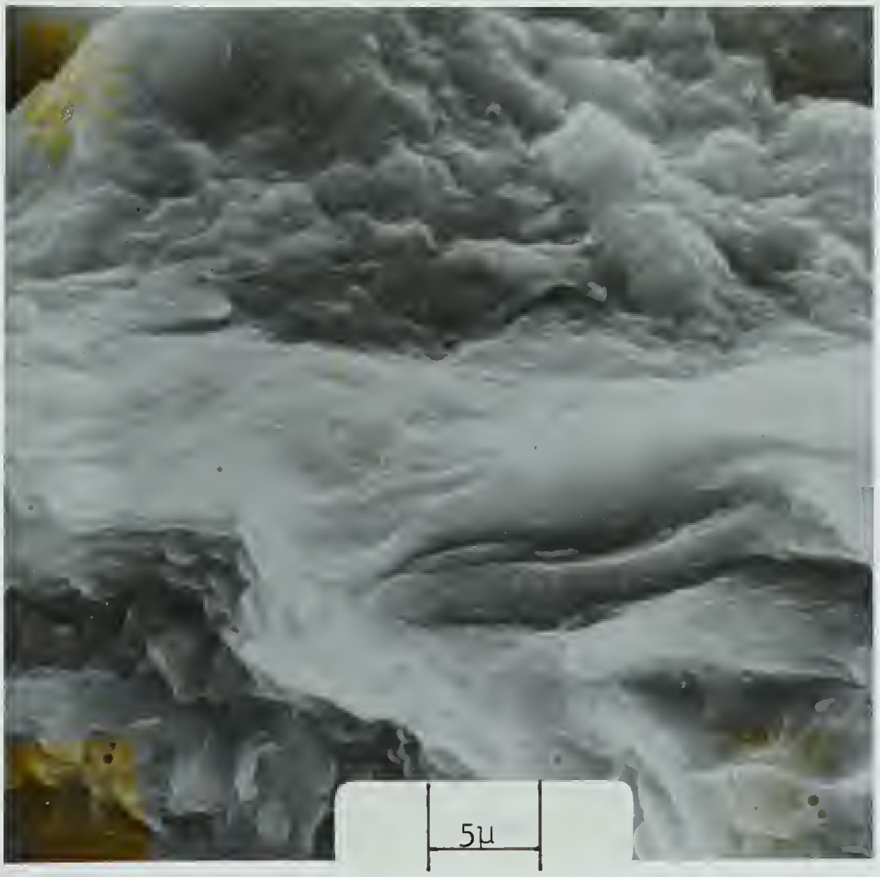


Plate 18.2 Edge of slickenside in Plate 18.1. Magnification 2.4K. (Site 2, Pedon 5, Bt_2 Horizon).

A single ped from the Bt_2 horizon of pedon 5 at Site 2 was fractured artifically by a sharp pin driven normal to the cutanic surface of the ped. Plate 19.1 at 2.7K magnification is a photomicrograph of the argillan at a 45° angle from the cutanic plane, and displays the characteristic smooth continuous orientation of the feature.

Plate 19.2 at a magnification of 2.4K is a photomicrograph of the inped fabric taken on the face which resulted from the artificial fracture. An abundance of what appears to be edge lines may be observed but show no consistency in orientation. Some individual structures are observable but in general the very dense packing of these plasmic materials conceals the anticipated crystalline structural units.

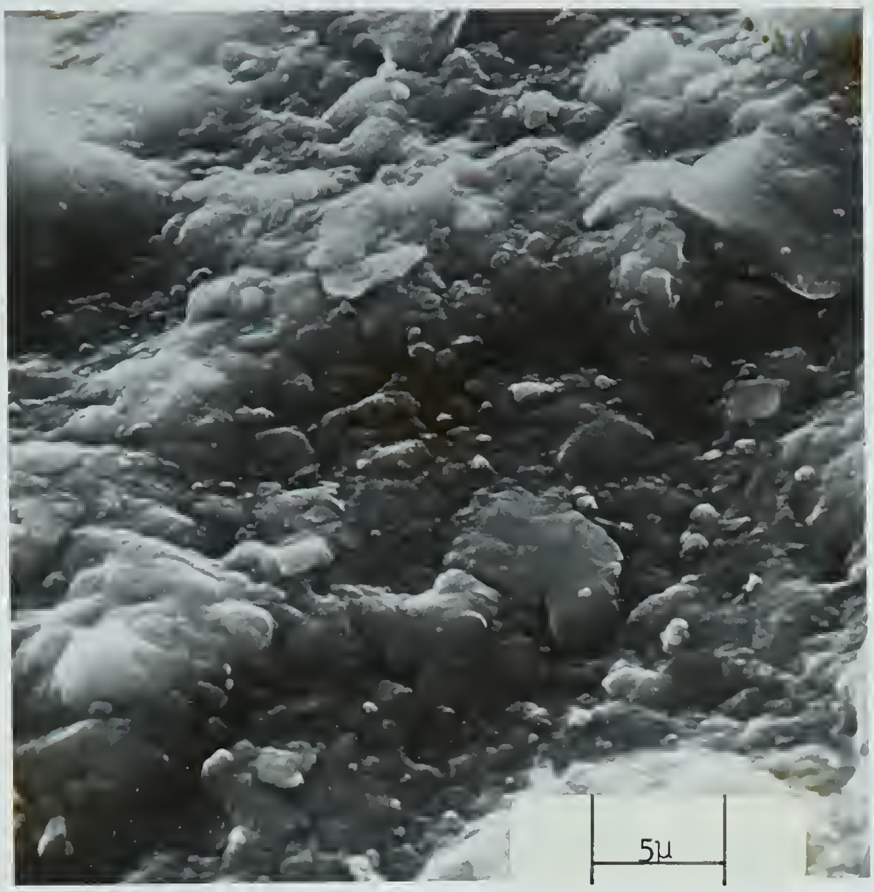


Plate 19.1 Plane argillan on ped surface (photographed 45° from normal). Magnification 2.7K. (Site 2, Pedon 5, Bt_2 Horizon)

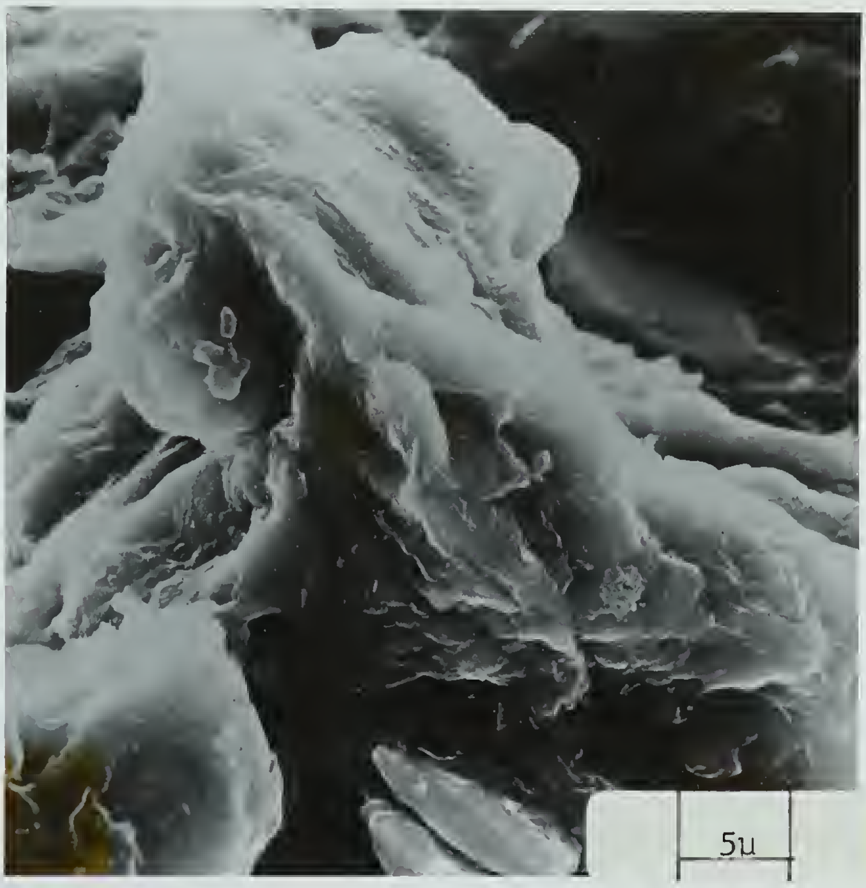


Plate 19.2 Inped plasma on artificial fracture surface of plane in Plate 19.1. Magnification 2.4K. (Site 2, Pedon 5, Bt_2 Horizon).

A ped sample from the Bt_1 horizon of pedon 1 at Site 3, which by visual observation appeared to be disintegrating, was selected for investigation through the use of the scanning electron microscope. Plate 20.1 at a magnification of 2.6K is a representative scanning electron micrograph of the face of the largest remaining portion of the ped taken at an angle of 45° from the plane. This face, which represents a natural failure in the ped, appears very similar to the slickenside represented in Plate 18.1 from Site 2. The smooth nature of the surface, lack of individual structures and dense packing of the plasmic constituents suggest a smooth and continuous fracture. Some linear orientation is observable but does not compare with some of the illuviation argillans presented previously. Further down in the ped, relative to the pedon, an abundance of smaller remnants of the disintegrating ped were examined.

Plate 20.1 Face of disintegrating ped (photographed 45° from normal). Magnification 2.6K. (Site 3, Pedon 1, Bt_1 Horizon).

Plate 21.1 at 1.2K magnification is a representative micrograph of a face of a smaller fragment. The appearance of this material is suggestive of inped plasma as was shown in the artificially fractured ped in Plate 19.2. It suggests that some force had caused the ped to disintegrate in a similar manner as the artificially induced fracture. As was the case in Plate 19.2 this plasmic material appears densely packed and randomly oriented. Some individual structures are observable but for the most part are concealed in the random array of materials.

Plate 21.2 at a magnification of 250x is a micrograph of a skeleton grain protruding from the surface of one of the fragments of this disintegrating ped. The array of plasmic substances is again suggestive of the artificially induced fracture in Plate 19.2. The most noteworthy comparison to be made is with Plates 9.1 and 9.2 of soils from Site 1. Micromorphological observation suggested the abundance of skeletal cutans at Site 1 and their near absence in Bt horizons in Sites 2 and 3. Plate 21.2 reveals no large degree of orientation of plasma to the skeletal grain and in comparison with Plates 9.1 and 9.2 confirms micromorphological observations.

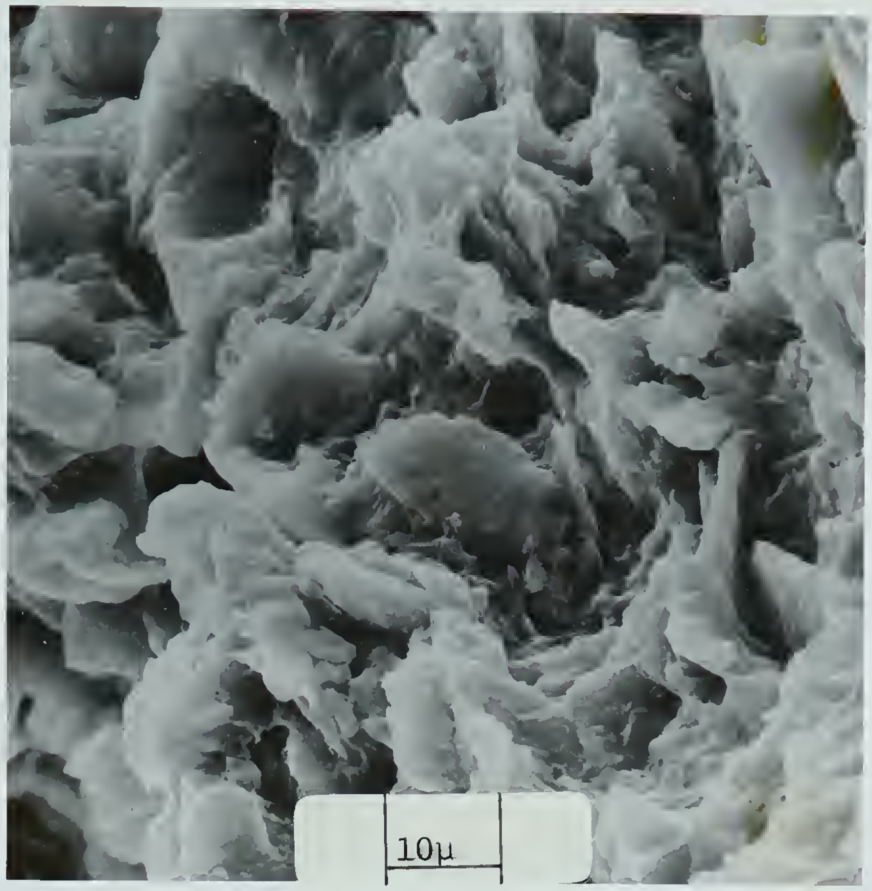


Plate 21.1 Fracture face of ped fragment (natural fracture). Magnification 1.2K. (Site 3, Pedon 1, Bt_1 Horizon).

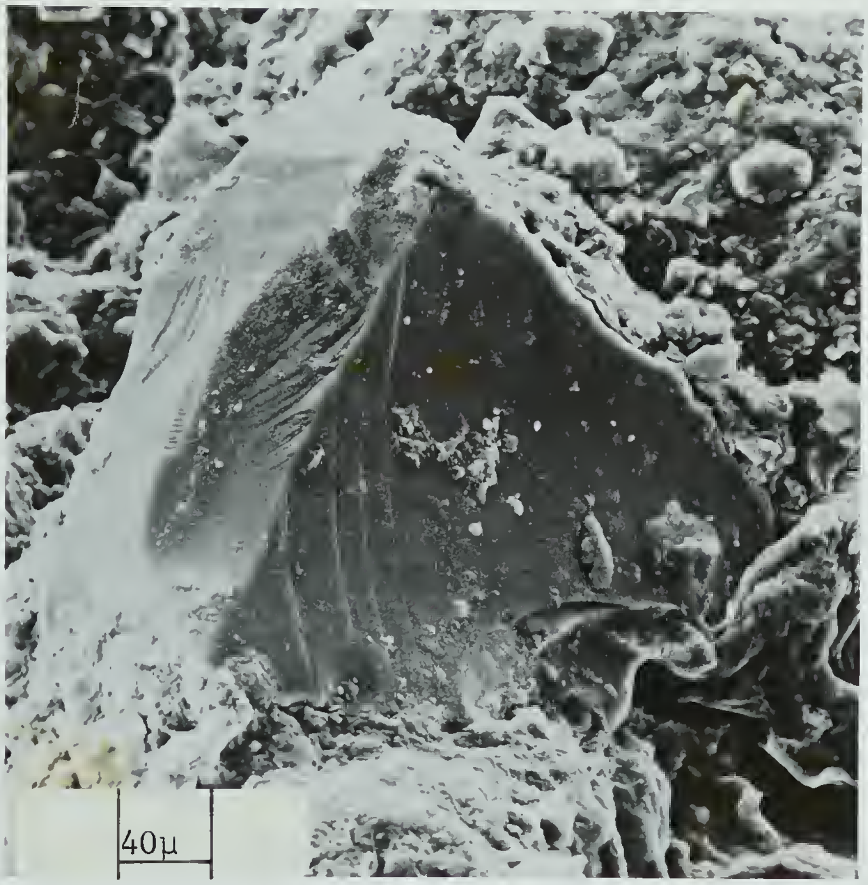


Plate 21.2 Skeleton grain protruding from plasma in disintegrating ped (Plate 20.1). Magnification 250x. (Site 3, Pedon 1, Bt_1 Horizon).

Plates 22.1 and 22.2 at magnifications of 7K and 1.6K, respectively are micrographs of two ped faces on a ped from the Bt_3 horizon of pedon 1 at Site 3. Plate 22.1 represents a photomicrograph of a cutanic surface on the ped taken normal to the plane of the cutan and shows the face to face orientation of the individual clay sized structural units and the smooth continuous nature of these surfaces. As was reported in the micromorphology section the occurrence of plane argillans diminished with depth in these pedons. Plate 22.2 represents a planar surface of the ped without cutans. If compared to inped materials in Plates 19.2 and 21.1 this surface appears to have the same topographic features. More face to face orientation is observable than in inped material however, and the orientation pattern appears more uniform and continuous.

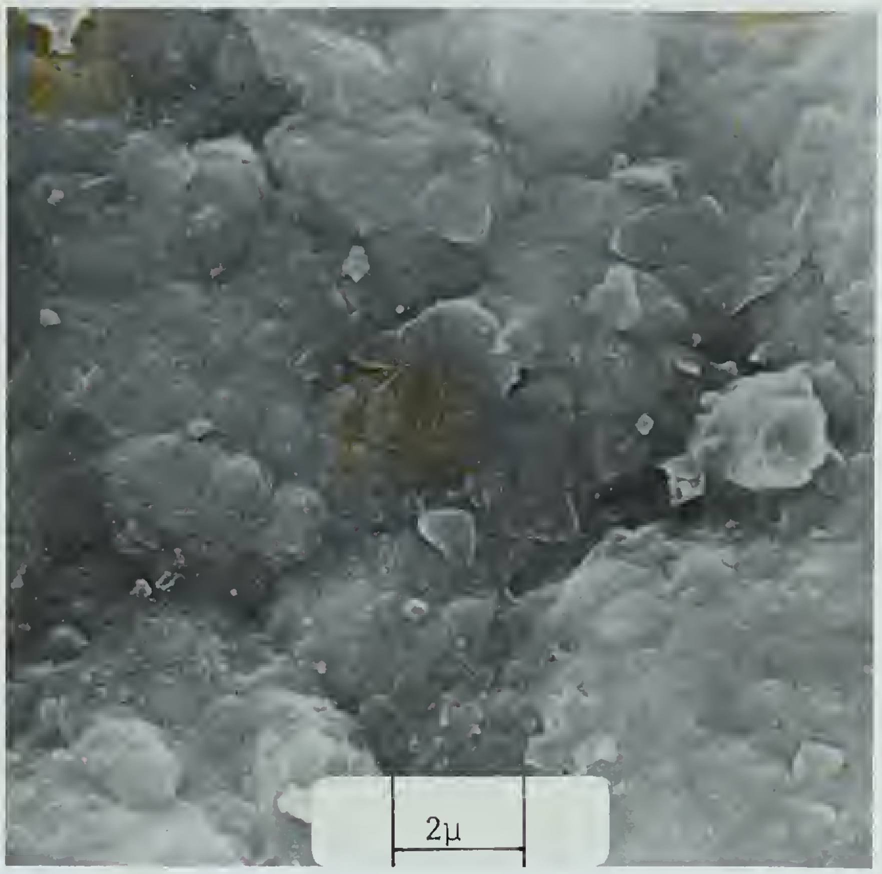


Plate 22.1 Plane argillan (photographed from the normal). Magnification 7K. (Site 3, Pedon 1, Bt_3 Horizon).

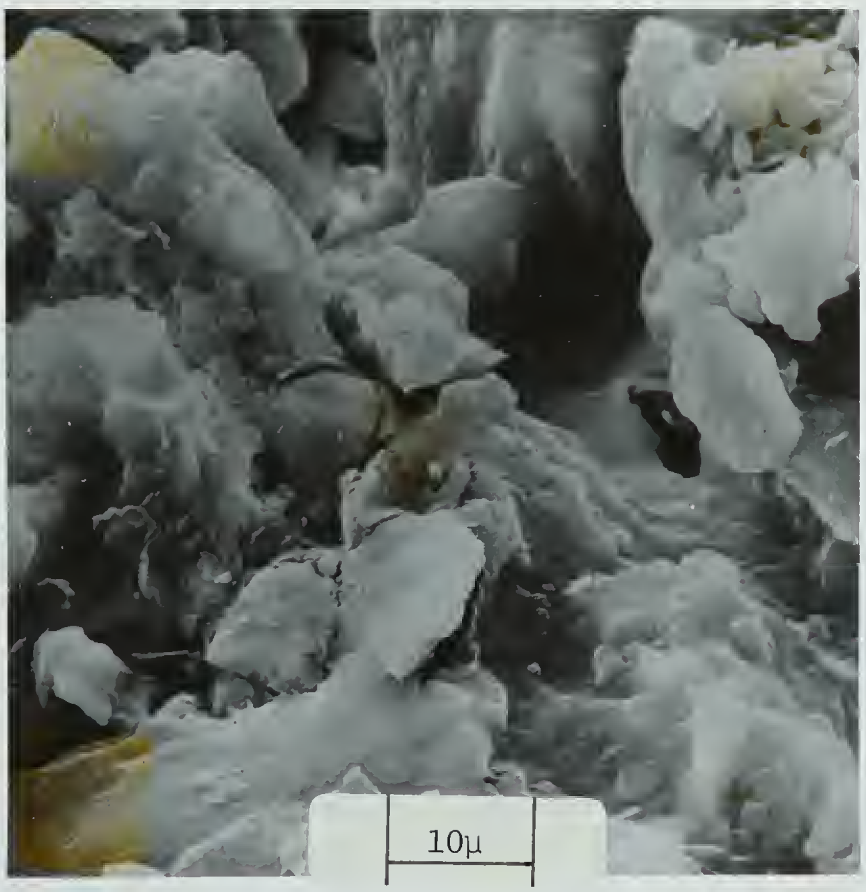


Plate 22.2 Ped surface without cutans. Magnification 1.6K. (Site 3, Pedon 1, Bt_3 Horizon).

V. SOIL CLASSIFICATION

Criteria for Bt horizons, as presented by the Canadian Soil Survey Committee (1970), and criteria for argillic horizons as presented by the Soil Survey Staff (1967) are met, with the exception of horizons designated Bt_{gj} in pedon 5 at Site 3, referred to previously as Bt. Tables 3, 4, and 5 present data for pedons at Sites 1, 2, and 3, respectively, which reveal the increasing clay content below the Ae horizon and the increase in the fine clay to coarse clay ratio which maximizes in the Bt and decreases with increasing depth to the parent material. The thickness and structure of Bt horizons and the absence of lithologic discontinuities as presented on Pages A2 to A15 in the Appendix, and the presence of greater than one percent oriented clays on vertical and horizontal faces of peds, as presented in Tables 10, 11, and 12 for Bt horizons in pedons at Sites 1, 2, and 3, respectively, fulfill the requirements of both systems of classification. Horizons designated Bt_{gj} in pedon 5 at Site 3 (Page A16 of Appendix) meet the requirements of an argillic horizon as proposed by the Soil Survey Staff (1967) and the criteria for Bt_{gj} horizons as presented by the Canadian Soil Survey Committee (1970), in that criteria for Bt are met and the horizons are mottled but do not show the neutral colors of intense reduction.

Pedons 1 to 5, inclusive, of the Coalspur Series investigated at Site 1, pedons 1 to 5, inclusive, of the Hubalta Series investigated at Site 2 and pedons 1 to 4, inclusive, of the Hubalta Series at Site 3 satisfy the requirements for classification as Orthic Gray Wooded at the subgroup level of abstraction in the System of Soil Classification

of Canada. This classification is validated in that these soils have an organic surface horizon (L-H), light colored Ae and Bt horizons, as presented in Appendix A (pages A2 to A15, inclusive). The Ah horizon present in pedons at Site 3 is less than 2 inches in thickness and the Ae often overlies an AB or BA horizon. In addition the Ae has a dry color of greater than 5.5 and except for the Coalspur Series a chroma of less than 3.0. Pedon 5 at Site 3 of the Bremay Series meets the requirements for the Gleyed Gray Wooded subgroup as presented by the Canadian Soil Survey Committee (1970). Coalspur and Hubalta soils, meeting the requirements for the Orthic Gray Wooded subgroup of the Canadian system of classification also meet the requirements for the Typic Cryoboralf subgroup of the 7th Approximation. Similarly the Bremay Series meets the requirements of the Aquic Cryoboralf subgroup as presented by the Soil Survey Staff (1967).

SUMMARY AND CONCLUSIONS

Soils of the Gray Wooded Great Group of the Luvisolic Order in the System of Soil Classification for Canada possess a characteristic argillic horizon (or horizons), generally attributed to translocation of clay size particles by acidic decomposition products of forest vegetation. The objective of the study was to investigate Bt horizons of macromorphologically characterized Gray Wooded soils from three different sites, two of which had similar parent material (a till from Continental origin) and the third a till from Cordilleran origin, by physical, chemical, and microscopic means for purposes of detailed comparison.

Macromorphological analysis separated the three soils on the basis of pedons with 1, 2, and 3 Bt horizons for Sites 1, 2, and 3, respectively. Bulk density measurements revealed a comparative difference in the Bt horizons with the pedons of Site 1 having a lesser density than the pedons at Site 2 and 3. Bulk densities corrected for fragments greater than 2mm equivalent spherical diameter showed a larger proportion of coarse fragments in the Bt horizons at Site 1. Particle size analysis showed a gradation in total clay with the least total clay at Site 1 and the largest amount at Site 3 and an opposite relationship for the sand size fraction. The fine clay to coarse clay ratio increased with depth in the pedon and reached a maximum at Sites 2 and 3 in the lower Bt's and declined with increasing depth. The least values for the fine clay to coarse clay ratios occurred at Site 1 and maximized at Site 3 as did the cation exchange capacity as estimated by sums of exchangeable

cations, supporting the proposition of fine clay illuviation proposed by Pawluk (1961). X-ray diffraction analysis of total clay samples from pedons at the three sites showed a great deal of similarity between the two sites with similar parent material but greater amounts of amorphous clay size materials at Site 1 and lesser amounts of clay minerals.

Descriptive micromorphological analysis showed comparative differences between the Bt horizons of pedons at Site 1 and the other sites and gave some insight into possible processes of pedogenesis. Strongly oriented void argillans, generally indicative of illuviation were present in Bt horizons at all three sites. The discontinuity of these argillans in Bt horizons at Site 1 and the presence of embedded grain cutans in addition to structure of aggregates and pore space suggest the additional pedogenic process of nondestructive mass wasting. Illuviation is suggested as the primary pedogenic process in pedons at Site 2 by the sharpness of boundary between void argillans and non-cutanic material. Plasma separations in the Bt horizons at this site suggest the additional factor of stresses operative in fabric formation. Illuviation was suggested as the dominant pedogenic process in soils at Site 3 and the Bt_1 horizon was described as more BA in character by the lack of surface cutans and a greater abundance of pores.

Modal analysis based on thirteen variables and 400 counts per thin section measured similarities and differences which existed within horizons at each individual site, between horizons within pedons at Sites 2 and 3, among pedons for similar horizons within sites, and among the sites. Some of the results obtained revealed:

1. The mineral fraction of the skeleton remained fairly constant with increasing depth in the pedon at the three sites.

2. Rock fragment values generally increased with depth at all three sites.

3. Orthovughs represented less than one percent of the total thin section in all three sites and had a large coefficient of variation.

4. The occurrence of total cutans showed the same trend as fine clay content offering additional support to the process of illuviation at all three sites.

5. Organic matter represented only a small proportion of the fabric of Bt horizons and occurred randomly with respect to depth, horizon, and pedon at all three sites.

Scanning electron micrographs were taken on selected samples from Bt horizons of pedons at the three sites. The topographic nature of exped surfaces confirmed the optical orientation in argillans as observed from extinction phenomena. Slickensides had a different topographic nature than cutanic surfaces.

LITERATURE CITED

Allison, L.E., W.B. Bollen, and C.D. Moodie. 1965. Total carbon. In: Methods of Soil Analysis, Part II. Chemical and Microbiological Properties, Black et al. (ed.). A.S.A. Monograph 9, Amer. Soc. Agron., Madison, Wisconsin.

Anderson, D.M. and R.R. Binnie. 1961. Modal analysis of soils. Soil Sci. Soc. Amer. Proc. 25: 499-503.

Association of Official Agricultural Chemists. 1955. Official methods of analysis. 8th ed., Washington 4, D.C.

Bartelli, L.J. and R.T. Odell. 1960. Laboratory studies and genesis of a clay-enriched horizon in the lowest part of the solum of some Brunizem and Gray-Brown Podzolic soils in Illinois. Soil Sci. Soc. Amer. Proc. 24: 390-395.

Baver, L.D. 1959. Soil Physics. 3rd ed. John Wiley and Sons, New York, N.Y.

Beke, G.J. 1969. Soils of three experimental watersheds in Alberta and their hydrologic significance. Unpublished Ph.D. Thesis, Univ. of Alta.

Beke, G.J. and M.A. Zwarich. 1971. Chemical and mineralogical characteristics of cutans from B horizons of three Manitoba soils. Can. J. Soil Sci. 51: 221-228.

Blake, G.R. 1965. Bulk Density. In: Methods of Soil Analysis, Part I. Physical and Mineralogical Properties, Black et al. (ed.). A.S.A. Monograph 9, Amer. Soc. Agron., Madison, Wisconsin.

Brewer, R. 1956. A petrographic study of two soils in relation to their origin and classification. J. Soil Sci. 7: 268-279.

Brewer, R. 1960. The petrographic approach to the study of soils. Trans. Seventh Int. Cong. Soil Sci. Madison 1: 1-13.

Brewer, R. 1964a. Fabric and mineral analysis of soils. John Wiley and Sons, Inc., New York.

Brewer, R. 1964b. Classification of plasmic fabrics of soil materials. In A. Jongerius (ed.), Soil Micromorphology. Elsevier Publ. Co.: 95-108.

Brewer, R. 1968. Clay illuviation as a factor in particle-size differentiation in soil profiles. 9th Int. Cong. Soil Sci. Trans., Adelaide, IV: 489-501.

Brewer, R. and A.D. Haldane. 1957. Preliminary experiments in the development of clay orientation in soils. Soil Sci. 84: 301-309.

Brewer, R. and J.R. Sleeman. 1960. Soil structure and fabric: their definition and description. J. Soil Sci. 11: 172-185.

Brewer, R. and J.R. Sleeman. 1969. The arrangement of constituents in Quaternary soils. Soil Sci. 107: 435-442.

Brown, J.C. 1943. A rapid method of determining exchangeable and total exchangeable bases of soils. Soil Sci. 56: 353-357.

Buckman, H.O. and N.C. Brady. 1968. The nature and properties of soils. 8th Edition. The Macmillan Co., New York.

Buol, S.W. and F.D. Hole. 1959. Some characteristics of clay skins on peds in the B-horizon of a Gray-Brown Podzolic soil. Soil Sci. Soc. Amer. Proc. 23: 239-241.

Buol, S.W. and F.D. Hole. 1961. Clay skin genesis in Wisconsin soils. Soil Sci. Soc. Amer. Proc. 25: 377-379.

Canadian Meteorological Service. 1968. Climatic Norms, Vol 1, 2, and 6. Toronto, Ontario.

Canadian Soil Survey Committee. 1970. The System of Soil Classification for Canada. Canada Department of Agriculture.

Cescas, M.P., E.H. Tyner, and R.S. Harmer III. 1970. Ferromanganiferous soil concretions: A scanning electron microscope study of their micropore structures. Soil Sci. Soc. Amer. Proc. 34: 641-644.

Chayes, F. 1956. Petrographic modal analysis: An elementary statistical appraisal. John Wiley and Sons Inc., New York; Chapman and Hall Ltd., London.

Day, P.R. and G.C. Holmgren. 1952. Microscopic changes in soil structure during compression. Soil Sci. Soc. Amer. Proc. 16: 73-77.

Dumanski, J. 1970. A micromorphological investigation on the genesis of soils developed on calcareous aeolian material. Unpublished Ph.D. Thesis, Univ. of Alta.

Ehrlich, W.A., H.M. Rice, and J.H. Ellis. 1955. Influence of the composition of parent materials on soil formation in Manitoba. Can. J. Agric. Sci. 35: 407-421.

Gile, L.H. and R.B. Grossman. 1968. Morphology of the argillic horizon in desert soils of southern New Mexico. Soil Sci. 100: 6-15.

Gillespie, J.A. and D.E. Elrick. 1968. Micromorphological characteristics of an Oneida soil profile. Can. J. Soil Sci. 48: 133-142.

Gillott, J.E. 1969. Study of the fabric of fine-grained sediments with the scanning electron microscope. Nat. Res. Cou. of Can. Research Paper No. 389.

Gillott, J.E. 1970. Fabric of leda clay investigated by optical, electron-optical, and x-ray diffraction methods. Nat. Res. Cou. of Can. Research Paper No. 448.

Gravenor, C.P. and L.A. Bayrock. 1955. Use of indicators in determination of ice-movement directions in Alberta. Geol. Soc. Amer. Bull. 66: 1325-8.

Grossman, R.B., R.T. Odell, and A.H. Beavers. 1964. Surfaces of peds from B horizons of Illinois soils. Soil Sci. Soc. Amer. Proc. 28: 792-798.

Harpstead, M. and R.H. Rust. 1964. A pedological characterization of five profiles in gray wooded soils area of Minnesota. Soil Sci. Soc. Amer. Proc. 28: 113-118.

Heil, R.D. and G.J. Buntley. 1965. A comparison of the characteristics of the ped faces and ped interiors in the B horizon of a chestnut soil. Soil Sci. Soc. Amer. Proc. 29: 583-587.

Hendricks, S.B., J.G. Cady, and K.W. Flach. 1962. Petrographic studies of mineral translocation in soils. Trans. Joint Meeting Comm. IV and V, Int. Soc. Soil Sci., Palmerston North, New Zealand.

Hole, F.D. 1961. A classification of pedoturbations and some other processes and factors of soil formation in relation to isotropism and anisotropism. Soil Sci. 91: 375-377.

Innes, R.P. and D.J. Pluth. 1970. Thin section preparation using an epoxy impregnation for petrographic and electron microprobe analysis. Soil Sci. Soc. Amer. Proc. 34: 483-485.

Jackson, M.L. 1958. Soil chemical analysis. Prentice-Hall Inc., Inglewood Cliffs, New Jersey.

Kittrick, J.A. and E.W. Hope. 1963. A procedure for the particle-size separation of soils for x-ray diffraction analysis. Soil Sci. 96: 319-325.

Knox, E.G., J.F. Corliss, and J.M. Williams. 1965. Dark colored, acid, forest soils of western Oregon. Soil Sci. Soc. Amer. Proc. 29: 732-736.

Kubiena, W.L. 1938. Micropedology. Collegiate Press Inc., Ames, Iowa.

Kubiena, W.L. 1964. Role and mission of micromorphology and microscopic biology in modern soil science. In A. Jongerius (ed.), Soil Micromorphology. Elsevier Publ. Co., 1-14.

Lutz, J.F. 1947. Apparatus for collecting undisturbed soil samples. Soil Sci. 64: 399-401.

Lynn, W.C. and R.B. Grossman. 1970. Observations of certain soil fabrics with the scanning electron microscope. Soil Sci. Soc. Amer. Proc. 34: 645-648.

Moss, E.H. 1955. The vegetation of Alberta. Bot. Rev. 21(9): 493-567.

Moss, E.H. 1959. Flora of Alberta. University of Toronto Press.

McCaleb, S.B. 1954. Profile studies of normal soils of New York: IV Mineralogical properties of the gray-brown podzolic-brown podzolic soil sequence. Soil Sci. 77: 319-333.

McCaleb, S.B. 1959. The genesis of the Red-Yellow Podzolic soils. Soil Sci. Soc. Amer. Proc. 23: 164-168.

Parfenova, E.I. and E.A. Yarilova. 1962. Mineralogical investigations in soil science. (Translated from Russian.) Isreal Program for Scientific Translations (1965).

Pawluk, S. 1960. Characteristics of gray wooded soils developed from glacial till deposits in the Peace River district and north-central regions of Alberta. Trans. Seventh Int. Cong. Soil Sci. Madison IV: 314-323.

Pawluk, S. 1961. Mineralogical composition of some Gray Wooded soils developed from glacial till. Can. J. Soil Sci. 41: 228-240.

Peech, M., R.A. Olsen, and G.H. Bolt. 1953. The significance of potentiometric measurements involving liquid junction in clay and soil suspensions. Soil Sci. Soc. Amer. Proc. 17: 214-218.

Pettapiece, W.W. 1970. Pedological investigations in the front ranges of the Rocky Mountains along the North Saskatchewan River Valley. Unpublished Ph.D. Thesis, Univ. of Alta.

Rode, A.A. 1964. Podzolization and lessivage. Soviet Soil Sci. 1964(7): 660-671.

Roed, M.A. 1968. Surficial geology of the Edson-Hinton area, Alberta. Unpublished Ph.D. Thesis, Univ. of Alta.

Soil Science Society of America. 1970. Glossary of soil science terms. Soil Sci. Soc. Amer. 677 South Segoe Road, Madison, Wisc.

Soil Survey Staff. 1967. Supplement to soil classification system (7th Approximation). Soil Conservation Service, U.S. Department of Agriculture.

Sleeman, J.R. 1963. Cracks, peds, and their surfaces in some soils of the Riverine Plain, New South Wales. Aust. J. Soil Res., Vol 1, No. 1: 91-100.

St. Arnaud, R.J. and E.P. Whiteside. 1963. Physical breakdown in relation to soil development. J. Soil Sci. 14: 267-281.

St. Arnaud, R.J. and E.P. Whiteside. 1964. Morphology and genesis of a Chernozem to Podzolic sequence of soil profiles in Saskatchewan. Can. J. of Soil Sci. Vol. 44: 88-89.

Stephen, I. 1960. Clay orientation in soils. Science Progress. Vol. 48: 322-331.

Thorp, J., L.E. Strong, and E.G. Amble. 1957. Experiments in soil genesis--the role of leaching. Soil Sci. Soc. Amer. Proc. 21: 99-103.

Thorp, J., J.C. Cady, and E.E. Gamble. 1959. Genesis of miami silt loam. Soil Sci. Soc. Amer. Proc. 23: 156-161.

Toogood, J.A. and T.W. Peters. 1953. Comparison of methods of mechanical analysis of soils. Can. J. Agric. Sci. 33: 159-171.

Twardy, A.G. 1969. A comparative study of glacial till parent material in west-central Alberta. Unpublished M.Sc. Thesis, Univ. of Alta.

Wynnyk, A., J.D. Lindsay and W. Odynsky. 1969. Soil survey of the Whitecourt and Barrhead area. Res. Cou. of Alta. Report No. 90

APPENDIX A

Pedon Macromorphology

PEDON MACROMORPHOLOGY

SITE 1
PEDON 1
SERIES: Coalspur

Horizon	Depth Inches	
L-H	2-0	Sphagnum moss with appreciable amounts of Labrador Tea and Bearberry, some grasses and herbs.
Ae_1	0-3	Grayish brown (10YR 5/2 m), pale brown (10YR 6/3 d) silt loam; moderate medium subangular blocky, breaking to weak fine platy; very friable; clear, smooth boundary; pH 4.9.
Ae_2	3-6½	Yellowish brown (10YR 5/4 m), light yellowish brown (10YR 6/4 d) silt loam; moderately developed medium to fine platy, breaking to fine granular; very friable; horizon boundary indistinct; pH 4.7.
AB	6½-9	Yellowish brown (10YR 5/4 m), light yellowish brown (10YR 6/4 d) loam; weak fine subangular blocky, breaking to coarse platy and granular; friable; horizon boundary indistinct.
Bt	9-19	Light olive brown (2.5Y 5/4 m), light yellowish brown (10YR 6/4 d) loam; weak fine to medium subangular blocky, breaking to moderate fine granular to crumb; friable; plentiful, very fine, random, inped and exped (inped and exped on subangular blocky but exped on granular), roots, with few fine and medium, random, inped, roots; many, very fine, discontinuous, inped (inped on subangular blocky structure but inped and exped on granular structure), simple vesicular and dendritic interstitial pores; horizon boundary indistinct; pH 4.8.
BC	19+	Light olive brown (2.5Y 5/4 m), light yellowish brown (10YR 6/4 d) loam; moderate fine sub-angular blocky, breaking to crumb; friable; pH 4.9.

SITE 1
PEDON 2
SERIES: Coalspur

Horizon	Depth Inches	
L-H	2-0	Sphagnum moss with appreciable amounts of Labrador Tea and Bearberry, some grasses and herbs.
Ae_1	0-3	Brown (10YR 5/3 m), pale brown (10YR 6/3 d) silt loam; massive, breaking to weak fine platy and crumb; very friable; clear smooth boundary; pH 4.6.
Ae_2	3-9½	Brown (10YR 5/3 m), very pale brown (10YR 7/3 d) silt loam; moderate, fine platy, breaking to crumb and granular; very friable; horizon boundary indistinct; pH 4.5.
Bt	9½- 18½	Yellowish brown (10YR 5/4 m), light yellowish brown (10YR 6/4 d) loam; weak fine to medium subangular blocky, breaking to granular; friable, plentiful (on top of Bt), few (on bottom of Bt), very fine, random, inped and exped (inped and exped on subangular blocky but exped on granular) roots, with few, fine and medium, oblique, inped roots; many, very fine, discontinuous, inped (inped on subangular blocky structure but inped and exped on granular structure), simple vesicular and dendritic interstitial pores; horizon boundary indistinct; pH 4.7.
BC	18½+	Light olive brown (2.5Y 5/4 m), pale brown (10YR 6/3 d) loam; moderate fine subangular blocky, breaking to granular; friable; pH 4.8.

SITE 1
PEDON 3
SERIES: Coalspur

Horizon	Depth Inches	
L-H	3-0	Sphagnum moss with appreciable amounts of Labrador Tea and Bearberry, some grasses and herbs.
Ae_1	0-2	Brown (10YR 5/3 m), pale brown (10YR 6/3 d) silt loam; weak fine subangular blocky, breaking to very weak medium platy; very friable; clear, smooth boundary; pH 4.0.
Ae_2	2-6	Yellowish brown (10YR 5/4 m), light yellowish brown (10YR 6/4 d) silt loam; strong fine to medium platy, breaking to crumb; very friable; horizon boundary indistinct; pH 4.3.
AB	6-8½	Yellowish brown (10YR 5/4 m), light yellowish brown (10YR 6/4 d) loam; moderate coarse platey, breaking to granular and crumb; friable; horizon boundary indistinct.
Bt	8½-16	Yellowish brown (10YR 5/4 m), light yellowish brown (10YR 6/4 d) loam; weak fine subangular blocky, breaking to granular; friable; few, very fine, random inped and exped (inped and exped on subangular blocky but exped on granular) roots, with few fine, random, inped roots, with few, medium, oblique, inped roots; many, very fine, discontinuous, inped (inped on subangular blocky but inped and exped on granular structure), simple vesicular pores; horizon boundary indistinct; pH 4.7.
BC or Bt_2	16+	Yellowish brown (10YR 5/4 m), light yellowish brown (10YR 6/4 d) loam; moderate to strong angular to subangular blocky, breaking to granular; friable; pH 4.8.

SITE 1
PEDON 4
SERIES: Coalspur

Horizon	Depth Inches	
L-H	3-0	Sphagnum moss with appreciable amounts of Labrador Tea and Bearberry, some grasses and herbs.
Ae	0-12	Brown (10YR 5/3 m), very pale brown (10YR 7/3d) silt loam; strong fine platy, breaking to crumb; very friable; horizon boundary indistinct; pH 4.4.
Bt	12-22	Yellowish brown (10YR 5/4 m), light yellowish brown (10YR 6/4 d) loam; weak to moderate fine subangular blocky, breaking to granular; friable; very few, very fine, random inped and exped (inped and exped on subangular blocky but exped on granular) roots, with few, medium and fine, random, inped roots; many, very fine, discontinuous, inped (inped on subangular blocky but inped and exped on granular structure), simple vesicular and dendritic interstitial pores; horizon boundary indistinct; pH 4.7.
BC	22+	Yellowish brown (10YR 5/4 m), pale brown (10YR 6/3 d) loam; strong subangular and angular blocky, breaking to granular; friable; pH 4.8.

SITE 1
PEDON 5
SERIES: Coalspur

Horizon	Depth Inches	
L-H	2-0	Sphagnum moss with appreciable amounts of Labrador Tea and Bearberry, some grasses and herbs.
Ae	0-8	Yellowish brown (10YR 5/4 m), very pale brown (10YR 7/3 d) silt loam; moderate fine to medium platy, breaking to crumb; very friable; horizon boundary indistinct; pH 4.6.
Bt	8-18.	Yellowish brown (10YR 5/4 m) light yellowish brown (10YR 6/4 d) loam; moderate fine subangular blocky, breaking to granular, friable; few, very fine, random, inped and exped (inped and exped on subangular blocky but exped on granular) roots, with few fine and medium, random, inped roots; many, very fine, discontinuous, inped (inped on subangular blocky but inped and exped on granular structure), simple vesicular and dendritic interstitial pores; horizon boundary indistinct; pH 4.9.
BC	18+	Yellowish brown (10YR 5/4 m), light yellowish brown (10YR 6/4 d) loam; weak fine subangular blocky, breaking to granular; friable; pH 5.3.

SITE 2
PEDON 1
SERIES: Hubalta

Horizon	Depth Inches	
L-H	3-0	Deciduous leaf litter, partially decomposed in lower portion.
Ae_1	0-3	Yellowish brown (10YR 5/4 m), light brownish gray (10YR 6/2 d) silt loam; strong fine to medium platy; very friable; clear smooth boundary; pH 5.6.
Ae_2	3-8	Yellowish brown (10YR 5/4 m), pale brown (10YR 6/3 d) loam; weak medium platy, friable; clear smooth boundary; pH 4.5.
AB	8-11	Dark brown (10YR 4/3 m), pale brown (10YR 6/3 d) clay loam; weak fine subangular blocky; friable to firm; horizon boundary indistinct; pH 4.4.
Bt_1	11-18	Dark yellowish brown (10YR 4/4 m), brown (10YR 5/3 d) clay loam; strong medium subangular blocky; firm; abundant, very fine, random, exped roots; common, very fine, discontinuous, random, inped, simple, tubular pores with few, micro, exped, interstitial, dendritic pores; horizon boundary indistinct; pH 4.3.
Bt_2	18-24	Dark brown to brown (10YR 4/3 m), brown (10YR 5/3 d) clay loam; moderate medium subangular blocky; firm; few, very fine, random, exped roots, with very few, medium, random, exped roots; common, very fine, discontinuous, random, inped, simple, tubular pores with common, micro, exped, interstitial, dendritic pores; horizon boundary indistinct; pH 4.4.
BC	24-28	Olive brown (2.5Y 4/4 m), light olive brown (2.5Y 5/4 d) clay loam; strong coarse blocky to massive; firm; horizon boundary indistinct; pH 4.7.
C	28+	Olive brown (2.5Y 4/4 m), light olive brown (2.5Y 5/4 d) clay loam; common, fine, distinct, strong brown (10YR 5/8) mottles; massive to fragmental; firm; pH 5.9.

SITE 2
PEDON 2
SERIES: Hubalta

Horizon	Depth Inches	
L-H	5-0	Deciduous leaf litter, partially decomposed in lower portion.
Ae_1	0-2	Grayish brown (10YR 5/2 m), gray to light gray (10YR 6/1 d) silt loam; strong fine to medium platy; very friable; clear, smooth boundary; pH 5.9.
Ae_2	2-7	Yellowish brown (10YR 5/4 m), pale brown (10YR 6/3 d) silty clay loam; weak medium platy; friable; clear smooth boundary; pH 5.2
AB	7-9	Brown (10YR 5/3 m), pale brown (10YR 6/3 d) clay loam; weak fine subangular blocky; friable to firm; horizon boundary indistinct; pH 4.9.
Bt_1	9-19	Dark yellowish brown (10YR 4/4 m), yellowish brown (10YR 5/4 d) clay loam; strong medium subangular blocky; firm; abundant, very fine, random, exped roots, with few, coarse, random exped roots; few, very fine, discontinuous, verticle, inped, simple, tubular pores, with few, micro, exped, interstitial, dendritic pores; horizon boundary indistinct; pH 4.3.
Bt_2	19-30	Dark brown to brown (10YR 4/3 m), yellowish brown (10YR 5/4 d) clay loam; moderate to strong medium subangular blocky; firm; plentiful, very fine, random, exped roots, with few, coarse, random, exped roots; few, very fine, discontinuous, random, inped, simple, tubular pores, with common, micro, exped, interstitial dendritic pores; horizon boundary indistinct; pH 4.4.
BC	30-36	Olive brown (2.5Y 4/4 m), light olive brown (2.5Y 5/4 d) clay loam; strong coarse blocky to massive; firm; horizon boundary indistinct; pH 6.0.
C	36+	Olive brown (2.5Y 4/4 m), light olive brown (2.5Y 5/4 d) clay loam; many, medium, distinct, strong brown (7.5YR 5/8) mottles; massive; firm; pH 6.8.

SITE 2
PEDON 3
SERIES: Hubalta

Horizon	Depth Inches	
L-H	3-0	Deciduous leaf litter, partially decomposed in lower portion.
Ae	0-4	Yellowish brown (10YR 5/4 m), very pale brown (10YR 7/3 d) silt loam; strong fine to medium platy; very friable; clear smooth boundary; pH 4.5.
AB	4-6	Dark yellowish brown (10YR 4/4 m), pale brown (10YR 6/3 d) clay loam; weak fine subangular blocky to pseudo platy; friable; clear smooth boundary; pH 4.5.
Bt_1	6-13	Dark yellowish brown (10YR 4/4 m), pale brown (10YR 6/3 d) clay; strong medium subangular blocky; friable to firm; abundant, very fine, random, exped roots, with few to plentiful, medium, random, inped and exped roots, with very few to few, coarse, random, exped roots; common, very fine, discontinuous, random, inped, simple, tubular pores, with few, micro, exped, interstitial, dendritic pores; horizon boundary indistinct; pH 4.6.
Bt_2	13-26	Dark brown to brown (10YR 4/3 m), brown (10YR 5/3 d) clay loam; moderate fine to medium subangular blocky; friable to firm; plentiful to abundant, very fine, random, exped roots, with few, medium to coarse, random, inped and exped roots; common, very fine, discontinuous, random, inped, simple, tubular pores, with few, micro, exped, interstitial, dendritic pores; horizon boundary indistinct; pH 4.3.
BC	26-37	Dark brown (10YR 3/3 m), light olive brown (2.5Y 5/4 d) clay loam; medium coarse blocky to massive; friable to firm; clear smooth boundary; pH 5.2.
C	37+	Olive brown (2.5Y 4/4 m), light olive brown (2.5Y 5/4 d) clay loam; few, fine, prominent, red (10R 4/6) mottles; massive; friable; pH 6.7.

SITE 2
PEDON 4
SERIES: Hubalta

Horizon	Depth Inches	
L-H	2-0	Deciduous leaf litter, partially decomposed in lower portion.
Ae_1	0-3	Grayish brown (10YR 5/2 m), light brownish gray (10YR 6/2 d) silt loam; strong fine to medium platy; very friable; clear smooth boundary; pH 4.6.
Ae_2	3-7	Yellowish brown (10YR 5/4 m), very pale brown (10YR 7/3 d) clay loam; weak fine subangular blocky breaking to weak medium platy; friable; clear smooth boundary; pH 4.4.
AB	7-9	Yellowish brown (10YR 5/4 m), pale brown (10YR 6/3 d) clay; moderate medium subangular blocky; friable to firm; horizon boundary indistinct; pH 4.3.
Bt_1	9-17	Dark yellowish brown (10YR 4/4 m), brown (10YR 5/3 d) clay; strong fine to medium subangular blocky; firm; abundant, very fine, random, exped roots, with few, coarse, random, exped roots; common, very fine, discontinuous, random, inped, simple, tubular pores, with common, micro, exped, interstitial, dendritic pores; horizon boundary indistinct; pH 4.3.
Bt_2	17-24	Dark grayish brown (10YR 4/2 m), brown (10YR 5/3 d) clay; strong medium to coarse subangular blocky; firm to very firm; plentiful, very fine, random, exped roots, with very few, medium, random, inped and exped roots; common, very fine, discontinuous, random, inped, simple, tubular pores, with few, micro, exped, interstitial, dendritic pores, horizon boundary indistinct; pH 5.1.
BC	24-30	Olive brown (2.5Y 4/4 m), light olive brown (2.5Y 5/4 d) clay; moderate fine subangular blocky; firm; horizon boundary indistinct; pH 6.6.
C	30+	Olive brown (2.5Y 4/4 m), light olive brown (2.5Y 5/4 d) clay; many, coarse, distinct, yellowish red (5YR 5/8) mottles; fragmental; firm; pH 7.0.

SITE 2
PEDON 5
SERIES: Hubalta

Horizon	Depth Inches	
L-H	2-0	Deciduous leaf litter, partially decomposed in lower portion.
Ae_1	0-3	Pale brown (10YR 6/3 m), very pale brown (10YR 7/3 d) silt loam; strong medium platy; very friable; clear smooth boundary; pH 4.5.
Ae_2	3-7	Yellowish brown (10YR 5/4 m), pale brown (10YR 6/3 d) silt loam to loam; moderate medium platy; very friable; clear smooth boundary; pH 4.3.
AB	7-9	Dark brown to brown (10YR 4/3 m), pale brown (10YR 6/3 d) clay loam; moderate fine subangular blocky; friable; clear smooth boundary; pH 4.3.
Bt_1	9-14	Dark brown to brown (10YR 4/3 m), brown (10YR 5/3 d) clay; strong medium subangular blocky; firm to very firm; plentiful, very fine, random, exped roots, with few medium, random inped and exped roots; many, micro to very fine, discontinuous, random, inped, simple, tubular pores, with few, micro, exped, interstitial, dendritic pores; horizon boundary indistinct; pH 4.3.
Bt_2	14-27	Very dark grayish brown (10YR 3/2 m), brown (10YR 5/3 d) clay; strong medium to coarse subangular blocky; firm to very firm; plentiful, very fine, random, exped roots, with very few, medium, random, inped and exped roots; many, micro to very fine, discontinuous, random, inped, simple, tubular pores, with few, micro, exped, interstitial, dendritic pores; horizon boundary indistinct; pH 4.5.
BC	27-37	Dark grayish brown (2.5Y 4/2 m), light olive brown (2.5Y 5/4 d) clay; fragmental to massive; friable to firm; horizon boundary indistinct; pH 6.6.
C	37+	Olive brown (2.5Y 4/4 m), light olive brown (2.5Y 5/4 d) clay loam; few, fine, prominent, red (10R 4/6) mottles; massive, friable; pH 7.2.

SITE 3
PEDON 1
SERIES: Hubalta

Horizon	Depth Inches	
L-F	3-0	Organic matter partially decomposed in lower portion.
Ah	0-2	Very dark brown (10YR 2/2 m), very dark grayish brown (10YR 3/2 d) silt loam; granular to massive; very friable; abrupt smooth boundary; pH 5.5.
Ae	2-4½	Dark brown to brown (10YR 4/3 m), light gray (10YR 7/1 d) silt loam to loam; weak fine platy; friable; abrupt smooth boundary; pH 5.2.
AB	4½-9	Brown (10YR 5/3 m), light brownish gray (10YR 6/2 d) clay; weak fine subangular blocky; firm; abrupt smooth boundary; pH 5.0.
Bt_1	9-15	Dark grayish brown (10YR 4/2 m), grayish brown (10YR 5/2 d) clay; moderate fine subangular blocky; firm; few, micro to very fine, horizontal, exped roots, with very few, medium, vertical, inped roots; many, micro, exped, interstitial, dendritic pores; clear smooth boundary; pH 4.4.
Bt_2	15-22	Dark grayish brown (10YR 4/2 m), light brownish gray (10YR 6/2 d) clay; strong fine subangular blocky; firm; few, micro to very fine horizontal, exped roots, with very few, fine, vertical, inped roots; common, micro, exped, interstitial, dendritic pores; clear smooth boundary; pH 4.2.
Bt_3	22-31	Dark brown (10YR 3/3 m), brown (10YR 5/3 d) clay; strong medium subangular blocky; firm, few, micro to fine, horizontal, exped roots, with very few, fine, vertical, inped roots; common, micro, exped, interstitial, dendritic pores; clear smooth boundary; pH 4.3.
BC	31-39	Dark grayish brown (2.5Y 4/2 m), grayish brown (2.5Y 5/2 d) clay loam to clay; weak medium to coarse subangular blocky; firm to friable; clear smooth boundary; pH 4.2.
C	39+	Dark grayish brown (2.5Y 4/2 m), grayish brown (2.5Y 5/2 d) clay loam; massive; friable; pH 4.8.

SITE 3
PEDON 2
SERIES: Hubalta

Horizon	Depth Inches	
L-F	2-0	Organic matter partially decomposed in lower portion.
Ah	0-1½	Very dark brown (10YR 2/2 m), very dark grayish brown (10YR 3/2 d) silt loam; granular to massive; very friable; abrupt smooth boundary; pH 4.7.
Ae	1½-5	Dark grayish brown (10YR 4/2 m), light gray (10YR 7/1 d) silt loam; weak fine platy; friable; abrupt smooth boundary; pH 4.2.
AB	5-9½	Dark brown to brown (10YR 4/3 m), light brownish gray (10YR 6/2 d) clay loam; weak fine subangular blocky; firm; abrupt smooth boundary; pH 5.0.
Bt_1	9½-15	Dark grayish brown (10YR 4/2 m), grayish brown (10YR 4/2 d) clay; moderate fine subangular blocky; firm; few, micro to very fine, horizontal, exped roots, with very few, medium, vertical, inped roots; many, micro, exped, interstitial, dendritic pores; clear smooth boundary; pH 4.8.
Bt_2	15-23	Dark gray (10YR 4/1 m), grayish brown (10YR 5/2 d) clay; strong fine subangular blocky; firm; few, micro to very fine, horizontal, exped roots, with very few, fine vertical, inped roots; common, micro, exped, interstitial, dendritic pores; clear smooth boundary; pH 4.3.
Bt_3	23-31	Dark grayish brown (10YR 4/2 m), grayish brown (10YR 5/2 d) clay; strong medium subangular blocky; firm; few, very fine to fine, horizontal exped roots, with very few, fine, vertical, inped roots; common, micro, exped, interstitial, dendritic pores; clear smooth boundary; pH 4.3.
BC	31-40	Dark grayish brown (2.5Y 4/2 m), grayish brown (2.5Y 5/2 d) clay; weak medium subangular blocky; firm to friable; clear smooth boundary; pH 4.3.
C	40+	Olive brown (2.5Y 4/4 m), grayish brown (2.5Y 5/2 d) clay loam to clay; massive, friable; pH 5.2.

SITE 3
PEDON 3
SERIES: Hubalta

Horizon	Depth Inches	
L-F	2-0	Organic matter partially decomposed in lower portion.
Ah	0-1½	Very dark brown (10YR 2/2 m), very dark grayish brown (10YR 3/2 d) silt loam; granular to massive; very friable; abrupt smooth boundary; pH 6.4.
Ae	1½-5	Dark brown to brown (10YR 4/3 m), light brownish gray (10YR 6/2 d) silt loam to loam; weak fine platy; friable; abrupt smooth boundary; pH 6.5.
AB	5-9	Dark brown to brown (10YR 4/3 m), brown (10YR 5/3 d) clay loam; weak fine subangular blocky; firm; abrupt smooth boundary; pH 5.5.
Bt_1	9-15	Dark grayish brown (10YR 4/2 m), light brownish gray (10YR 6/2 d) clay; moderate fine subangular blocky; firm; few, micro, horizontal, exped roots, with few, fine to medium, vertical, inped roots; common, micro, exped, interstitial, dendritic pores; clear smooth boundary; pH 6.0.
Bt_2	15-22	Dark brown to brown (10YR 4/3 m), brown (10YR 5/3 d) clay; strong fine subangular blocky; firm; few, micro, horizontal, exped roots, with few, fine to medium, vertical, inped roots; common, micro, exped, interstitial, dendritic pores; smooth clear boundary; pH 4.9.
Bt_3	22-31	Dark brown to brown (10YR 4/3 m), brown (10YR 5/3 d) clay; strong medium subangular blocky; firm; few, micro, horizontal, exped roots, with few, fine to medium, vertical, inped roots; common, micro, exped, interstitial, dendritic pores; clear smooth boundary; pH 4.6.
BC	31-38	Olive brown (2.5Y 4/4 m), grayish brown (2.5Y 5/2 d) clay; weak medium subangular blocky; firm to friable; clear smooth boundary; pH 4.5.
C	38+	Dark grayish brown (2.5Y 4/2 m), grayish brown (2.5Y 5/2 d) clay; massive; friable; pH 5.1.

SITE 3
PEDON 4
SERIES: Hubalta

Horizon	Depth Inches	
L-F	2½-0	Organic matter partially decomposed in lower portion.
Ah	0-1	Very dark brown (10YR 2/2 m), very dark grayish brown (10YR 3/2 d) silt loam; granular to massive; very friable; abrupt smooth boundary; pH 5.1.
Ae	1-6	Grayish brown (10YR 5/2 m), light gray (10YR 7/1 d) silt loam to sandy loam; weak fine platy; friable abrupt smooth boundary; pH 5.2.
AB	6-8½	Brown (10YR 5/3 m), light gray (10YR 7/2 d) silt loam; weak fine subangular blocky; firm; abrupt smooth boundary; pH 5.5.
Bt_1	8½-16	Brown (10YR 5/3 m), pale brown (10YR 6/3 d) clay loam; moderate fine subangular blocky; firm; few, micro, horizontal, exped roots, with few, fine to medium, vertical, inped roots; common, micro, exped, interstitial, dendritic pores; clear smooth boundary; pH 5.2.
Bt_2	16-26	Dark grayish brown (10YR 4/2 m), grayish brown (10YR 5/2 d) clay; strong fine subangular blocky; firm; few, micro, horizontal, exped roots, with few, fine to medium, vertical, inped roots; common, micro, exped, interstitial, dendritic pores; smooth clear boundary; pH 4.7.
Bt_3	26-32	Dark brown to brown (10YR 4/3 m), grayish brown (10YR 5/2 d) clay; strong medium subangular blocky; firm; few, micro, horizontal, exped roots with few, fine to medium, vertical, inped roots; common, micro, exped, interstitial, dendritic pores; clear smooth boundary; pH 4.5.
BC	32-40	Dark grayish brown (2.5Y 4/2 m), grayish brown (2.5Y 5/2 d) clay; weak medium subangular blocky; firm to friable; clear smooth boundary; pH 4.5.
C	40+	Dark grayish brown (2.5Y 4/2 m), grayish brown (2.5Y 5/2 d) clay loam to clay; massive, friable; pH 5.8

SITE 3
PEDON 5
SERIES: Bremay

Horizon	Depth Inches	
L-F	2-0	Organic matter partially decomposed in lower portion.
Ah	0-2	Black (10YR 2/1 m), very dark grayish brown (10YR 3/2 d) silty clay loam; granular to massive; very friable; abrupt smooth boundary; pH 4.4.
Aegj	2-6	Dark grayish brown (10YR 4/2 m), light gray (10YR 7/2 d) silt loam; common medium distinct, yellowish brown (10YR 5/6) mottles; weak fine platy; friable; abrupt smooth boundary; pH 4.4.
ABgj	6-9	Dark grayish brown (10YR 4/2 m), light brownish gray (10YR 6/2 d) silt loam; few fine distinct, yellowish brown (10YR 5/6) mottles; weak fine subangular blocky; firm; abrupt smooth boundary; pH 4.8.
Btgj1	9-16	Dark brown to brown (10YR 4/3 m), grayish brown (10YR 5/2 d) clay; few fine faint yellowish brown (10YR 5/6) mottles; moderate fine subangular blocky; firm; few, micro to very fine, horizontal, exped roots, with very few, medium, vertical, inped roots; many micro, exped, interstitial, dendritic pores; clear smooth boundary; pH 4.5.
Btgj2	16-25	Very dark grayish brown (10YR 3/2 m), grayish brown (10YR 5/2 d) clay; few fine faint yellowish brown (10YR 5/6) mottles; strong fine subangular blocky; firm; few, micro to very fine, horizontal, exped roots, with very few, fine, vertical, inped roots; common, micro, exped, interstitial, dendritic pores; clear smooth boundary; pH 4.3.
Btgj3	25-33	Dark grayish brown (10YR 4/2 m), grayish brown (10YR 5/2 d) clay; few fine faint yellowish brown (10YR 5/6) mottles; strong, medium subangular blocky; firm; few, micro to fine, horizontal, exped roots, with very few, fine, vertical, inped roots; common, micro, exped, interstitial, dendritic pores; clear smooth boundary; pH 4.2.
BCgj	33-41	Dark grayish brown (2.5Y 4/2 m), grayish brown (2.5Y 5/2 d) clay; few fine faint yellowish brown (10YR 5/6) mottles; weak medium subangular blocky; firm to friable; clear smooth boundary; pH 4.3.
Cg	41+	Very dark grayish brown (2.5Y 3/2 m), grayish brown (2.5Y 5/2 d) clay; many medium prominent bluish gray (5B 5/1) mottles; massive; friable; pH 4.5.

APPENDIX B

Physical and Chemical Pedon Characterization

SITE 1
PEDON 1

Horizon		Ae_1	Ae_2	Bt	BC
Depth (in.)		0-3	3-6.5	9-19	19+
PHYSICAL ANALYSES					
Moisture Content % Dry Wt.		25.4*	-	16.2	-
Bulk Density gm/cc		1.18*	-	1.50	-
Corr. Bulk Density gm/cc		1.08	-	1.48	-
Mean Deviation Corr. Bulk Density		0.12	-	-	-
CHEMICAL ANALYSES					
pH †		4.9	4.7	4.8	4.9
% Total Carbon		1.69	0.78	0.18	0.20
% Nitrogen		0.09	0.06	0.03	0.02
C/N		18.8	13.0	6.0	10.0
Exchange	H	3.9	3.9	2.4	2.0
Analyses	Na	0.2	0.1	0.1	0.1
(meq/100 gm)	K	0.4	0.4	0.4	0.4
	Ca	5.4	5.1	10.5	11.9
	Mg	1.1	1.0	2.5	2.6
	S.E.C.	11.0	10.5	15.9	17.0
MECHANICAL ANALYSES					
% Sand	S	40*	34*	43*	48*
% Silt	Si	49*	53*	36*	34*
% Clay	C	11*	13*	21*	18*
% Fine Clay	FC	3*	3*	8*	4*
Si/C		4.5	4.1	1.7	1.9
FC/CC		0.38	0.30	0.62	0.29

* Mean of 3 replicates
† pH determined using 0.01 M $CaCl_2$ soil suspension

SITE 1
PEDON 2

Horizon		Ae1	Ae2	Bt	BC
Depth (in.)		0-3	3-9.5	9.5-18.5	18.5+
PHYSICAL ANALYSES					
Moisture Content % Dry Wt.		28.8*	-	22.5	-
Bulk Density gm/cc		1.31*	-	1.47	-
Corr. Bulk Density gm/cc		1.26*	-	1.27	-
Mean Deviation Corr. Bulk Density		0.08	-	-	-
CHEMICAL ANALYSES					
pH †		4.6	4.5	4.7	4.8
% Total Carbon		1.70	0.48	0.23	0.15
% Nitrogen		0.10	0.05	0.03	0.03
C/N		17.0	9.6	7.7	5.0
Exchange	H	5.4	2.9	2.6	2.1
Analyses	Na	0.3	0.1	0.1	0.1
(meq/100 gm)	K	0.4	0.2	0.4	0.3
	Ca	7.3	5.7	11.8	11.9
	Mg	1.5	1.3	3.0	2.9
	S.E.C.	14.9	10.2	17.9	17.3
MECHANICAL ANALYSES					
% Sand	S	37*	30*	40*	46*
% Silt	Si	49*	59*	38*	35*
% Clay	C	14*	11*	22*	19*
% Fine Clay	FC	5*	3*	8*	7*
Si/C		3.5	5.4	1.7	1.9
FC/CC		0.56	0.38	0.57	0.58

* Mean of 3 replicates
† pH determined using 0.01 M $CaCl_2$ soil suspension

SITE 1
PEDON 3

Horizon		Ae_1	Ae_2	Bt	BC
Depth (in.)		0-2	2-6	8.5-16.0	16+
PHYSICAL ANALYSES					
Moisture Content % Dry Wt.		26.6*	-	20.8	-
Bulk Density gm/cc		1.23*	-	1.47	-
Corr. Bulk Density gm/cc		1.22*	-	1.38	-
Mean Deviation Corr. Bulk Density		0.04	-	-	-
CHEMICAL ANALYSES					
pH †		4.0	4.3	4.7	4.8
% Total Carbon		2.41	1.07	0.27	0.18
% Nitrogen		0.12	0.08	0.03	0.03
C/N		20.1	13.4	9.0	6.0
Exchange	H	8.4	4.9	2.7	2.0
Analyses	Na	0.1	0.2	0.1	0.1
(meq/100 gm)	K	0.4	0.3	0.4	0.3
	Ca	6.0	10.5	11.4	9.9
	Mg	1.5	1.5	3.1	2.6
	S.E.C.	16.4	17.4	17.7	14.9
MECHANICAL ANALYSES					
% Sand	S	34*	35*	43*	47*
% Silt	Si	50*	50*	36*	35*
% Clay	C	16*	15*	21*	18*
% Fine Clay	FC	7*	6*	7*	5*
Si/C		3.1	3.3	1.7	3.6
FC/CC		0.78	0.67	0.50	0.38

* Mean of 3 replicates
† pH determined using 0.01 M $CaCl_2$ soil suspension

SITE 1
PEDON 4

Horizon		Ae	Bt	BC
Depth (in.)		0-12	12-22	22 +
PHYSICAL ANALYSES				
Moisture Content % Dry Wt.		25.0*	20.8	-
Bulk Density gm/cc		1.26*	1.55	-
Corr. Bulk Density gm/cc		1.23*	1.45	-
Mean Deviation Corr. Bulk Density		0.04	-	-
CHEMICAL ANALYSES				
pH †		4.4	4.7	4.8
% Total Carbon		0.59	0.26	0.15
% Nitrogen		0.05	0.03	0.03
C/N		11.8	8.7	5.0
Exchange	H	3.3	2.5	2.1
Analyses	Na	0.1	0.1	0.1
(meq/100 gm)	K	0.2	0.4	0.4
	Ca	5.4	11.8	11.9
	Mg	1.3	3.4	3.1
	S.E.C.	10.3	18.2	17.6
MECHANICAL ANALYSES				
% Sand	S	34*	46*	44*
% Silt	Si	55*	32*	34*
% Clay	C	11*	22*	22*
% Fine Clay	FC	3*	7*	8*
Si/C		5.0	1.5	1.5
FC/CC		0.38	0.47	0.50

* Mean of 3 replicates
† pH determined using 0.01 M $CaCl_2$ soil suspension

SITE 1
PEDON 5

Horizon		Ae	Bt	BC
Depth (in.)		0-8	8-18	18 +
PHYSICAL ANALYSES				
Moisture Content % Dry Wt.		17.5*	20.5	-
Bulk Density gm/cc		1.36*	1.30	-
Corr. Bulk Density gm/cc		1.23*	1.25	-
Mean Deviation Corr. Bulk Density		0.08*	-	-
CHEMICAL ANALYSES				
pH †		4.6	4.9	5.3
% Total Carbon		0.40	0.20	0.16
% Nitrogen		0.04	0.03	0.03
C/N		10.0	6.7	5.3
Exchange	H	3.1	2.3	1.9
Analyses	Na	0.1	0.1	0.2
(meq/100 gm)	K	0.2	0.4	0.4
	Ca	5.7	12.7	14.5
	Mg	1.3	3.3	3.3
	S.E.C.	10.4	18.8	20.3
MECHANICAL ANALYSES				
% Sand	S	34*	37*	38*
% Silt	Si	55*	37*	38*
% Clay	C	11*	26*	24*
% Fine Clay	FC	2*	11*	14*
Si/C		5.0	1.4	1.6
FC/CC		0.22	0.73	1.4

* Mean of 3 replicates
† pH determined using 0.01 M $CaCl_2$ soil suspension

SITE 2
PEDON 1

Horizon		Ae 1	Ae 2	AB	Bt1	Bt2	BC	C
Depth (in.)		0-3	3-8	8-11	11-18	18-24	24-28	28 +
PHYSICAL ANALYSES								
Moisture Content % Dry Wt.		16.9*	-	-	21.9*	23.0*	-	19.4*
Bulk Density gm/cc		1.42*	-	-	1.55*	1.53*	-	1.71*
Corr. Bulk Density gm/cc		1.40*	-	-	1.53*	1.52*	-	1.70*
Mean Deviation Corr. Bulk Density		0.06	-	-	0.02	0.01	-	0.03
CHEMICAL ANALYSES								
pH †		5.6	4.5	4.4	4.3	4.4	4.7	5.9
% Total Carbon		1.07	0.79	0.73	0.78	0.57	0.62	0.64
% Nitrogen		0.09	0.08	0.07	0.05	0.04	0.04	0.04
C/N		11.9	9.9	10.4	15.6	14.3	15.5	16.0
Exchange	H	1.5	3.8	5.2	4.8	4.5	3.0	0.9
Analyses	Na	0.1	0.1	0.1	0.2	0.2	0.2	0.2
(meq/100 gm)	K	0.4	0.4	0.3	0.3	0.3	0.3	0.3
	Ca	6.9	9.9	12.0	13.0	16.7	15.2	17.4
	Mg	1.3	2.6	4.3	4.5	5.9	5.3	5.9
	S.E.C.	10.2	16.8	21.9	22.8	27.6	24.0	24.7
MECHANICAL ANALYSES								
% Sand	S	44	39	36	34	29	33	33
% Silt	Si	50	39	33	32	34	33	32
% Clay	C	6	22	31	34	37	34	35
% Fine Clay	FC	2	19	25	29	28	25	15
Si/C		8.3	1.8	1.1	0.9	0.9	1.0	0.9
FC/CC		0.50	6.3	4.2	5.8	3.1	2.8	0.75

* Mean of 3 replicates
† pH determined using 0.01 M $CaCl_2$ soil suspension

SITE 2
PEDON 2

Horizon		Ae_1	Ae_2	AB	Bt_1	Bt_2	BC	C
Depth (in.)		0-2	2-7	7-9	9-19	19-30	30-36	36 +
PHYSICAL ANALYSES								
Moisture Content % Dry Wt.		24.2*	-	-	23.6*	22.3*	-	20.7*
Bulk Density gm/cc		1.34*	-	-	1.53*	1.60*	-	1.68*
Corr. Bulk Density gm/cc		1.33*	-	-	1.51*	1.59*	-	1.68*
Mean Deviation Corr. Bulk Density		0.04	-	-	0.03	0.02	-	0.00
CHEMICAL ANALYSES								
pH †		5.9	5.2	4.9	4.3	4.4	6.0	6.8
% Total Carbon		1.82	0.97	0.66	0.46	0.57	0.52	0.75
% Nitrogen		0.12	0.09	0.07	0.04	0.04	0.04	0.04
C/N		15.2	10.8	9.4	11.5	14.3	13.0	18.8
Exchange	H	1.3	2.5	2.8	4.8	4.3	1.1	0.3
Analyses	Na	0.1	0.0	0.2	0.2	0.2	0.2	0.2
(meq/100 gm)	K	0.3	0.4	0.3	0.2	0.4	0.3	0.3
	Ca	9.4	10.3	11.0	11.7	14.7	16.2	19.0
	Mg	1.6	3.4	4.0	4.5	5.7	5.6	6.2
	S.E.C.	12.7	16.6	18.3	21.4	25.3	23.4	26.0
MECHANICAL ANALYSES								
% Sand	S	42	26	29	34	37	32	34
% Silt	Si	51	41	36	29	27	30	32
% Clay	C	7	33	35	37	36	38	34
% Fine Clay	FC	2	9	12	17	16	15	13
Si/C		7.3	1.2	1.0	0.8	0.8	0.8	0.9
FC/CC		0.40	0.38	0.52	0.85	0.80	0.65	0.62

* Mean of 3 replicates
† pH determined using 0.01 M $CaCl_2$ soil suspension

SITE 2
PEDON 3

Horizon		Ae	AB	Bt_1	Bt_2	BC	C
Depth (in.)		0-4	4-6	6-13	13-26	26-37	37 +
PHYSICAL ANALYSES							
Moisture Content % Dry Wt.		18.1*	-	23.1*	23.4*	-	19.6*
Bulk Density gm/cc		1.37*	-	1.45*	1.49*	-	1.69*
Corr. Bulk Density gm/cc		1.36*	-	1.44*	1.47*	-	1.68*
Mean Deviation Corr. Bulk Density		0.01	-	0.05	0.03	-	0.05
CHEMICAL ANALYSES							
pH †		4.5	4.5	4.6	4.3	5.2	6.7
% Total Carbon		0.67	0.84	0.56	0.45	0.62	0.68
% Nitrogen		0.06	0.08	0.06	0.05	0.05	0.04
C/N		11.2	10.5	9.3	9.0	12.4	17.0
Exchange	H	2.9	3.3	3.5	4.4	2.1	0.2
Analyses	Na	0.1	0.1	0.2	0.2	0.2	0.2
(meq/100 gm)	K	0.2	0.3	0.4	0.4	0.4	0.3
	Ca	3.2	9.7	15.2	13.1	15.6	18.3
	Mg	0.9	2.9	5.1	4.8	5.9	4.8
	S.E.C.	7.3	16.3	24.4	22.9	24.2	23.8
MECHANICAL ANALYSES							
% Sand	S	38	27	26	33	31	38
% Silt	Si	53	41	32	30	31	32
% Clay	C	9	32	42	37	38	30
% Fine Clay	FC	3	10	20	19	21	18
Si/C		5.9	1.3	0.8	0.8	0.8	1.1
FC/CC		0.50	0.45	0.91	1.06	1.24	1.50

* Mean of 3 replicates
† pH determined using 0.01 M $CaCl_2$ soil suspension

SITE 2
PEDON 4

Horizon		Ae_1	Ae_2	AB	Bt_1	Bt_2	BC	C
Depth (in.)		0-3	3-7	7-9	9-17	17-24	24-30	30 +
PHYSICAL ANALYSES								
Moisture Content % Dry Wt.		17.9*	-	-	23.0*	21.3*	-	19.0*
Bulk Density gm/cc		1.35*	-	-	1.44*	1.55*	-	1.69*
Corr. Bulk Density gm/cc		1.33*	-	-	1.44*	1.54*	-	1.64*
Mean Deviation Corr. Bulk Density		0.04	-	-	0.02	0.01	-	0.03
CHEMICAL ANALYSES								
pH †		4.6	4.4	4.3	4.3	5.1	6.6	7.0
% Total Carbon		0.89	0.60	0.75	0.77	0.71	0.82	0.99
% Nitrogen		0.07	0.07	0.06	0.06	0.05	0.06	0.05
C/N		12.7	8.6	12.5	12.8	14.2	13.7	19.8
Exchange	H	2.8	3.7	5.6	5.3	2.4	0.2	0.2
Analyses	Na	0.1	0.1	0.1	0.1	0.1	0.1	0.2
(meq/100 gm)	K	0.3	0.3	0.4	0.5	0.4	0.4	0.4
	Ca	3.8	6.1	9.7	11.3	12.8	17.5	18.3
	Mg	1.0	2.6	4.3	5.3	5.7	5.6	5.4
	S.E.C.	8.0	12.8	20.1	22.5	21.4	23.8	24.5
MECHANICAL ANALYSES								
% Sand	S	34	30	23	20	24	22	22
% Silt	Si	53	39	33	32	30	35	36
% Clay	C	13	31	44	48	46	43	42
% Fine Clay	FC	3	14	22	25	22	20	19
Si/C		4.1	1.3	0.7	0.7	0.7	0.8	0.9
FC/CC		0.30	0.82	1.00	1.09	0.92	0.87	0.83

* Mean of 3 replicates
† pH determined using 0.01 M $CaCl_2$ soil suspension

SITE 2
PEDON 5

Horizon		Ae_1	Ae_2	AB	Bt_1	Bt_2	BC	C
Depth (in.)		0-3	3-7	7-9	9-14	14-27	27-37	37 +
PHYSICAL ANALYSES								
Moisture Content % Dry Wt.		18.2*	-	-	22.5*	21.1*	-	18.1*
Bulk Density gm/cc		1.38*	-	-	1.48*	1.48*	-	1.70*
Corr. Bulk Density gm/cc		1.37*	-	-	1.47*	1.47*	-	1.69*
Mean Deviation Corr. Bulk Density		0.05	-	-	0.04	0.08	-	0.01
CHEMICAL ANALYSES								
pH †		4.5	4.3	4.3	4.3	4.5	6.6	7.2
% Total Carbon		0.97	0.77	0.64	0.64	0.70	0.89	0.78
% Nitrogen		0.08	0.07	0.07	0.05	0.05	0.05	0.04
C/N		12.1	11.0	9.1	12.8	14.0	17.8	19.5
Exchange	H	3.1	4.8	5.0	4.9	4.0	0.2	0.1
Analyses	Na	0.1	0.0	0.1	0.1	0.1	0.1	0.1
(meq/100 gm)	K	0.3	0.3	0.3	0.4	0.4	0.4	0.4
	Ca	2.5	4.5	7.4	11.3	12.1	15.2	22.6
	Mg	1.0	1.8	3.5	5.6	5.9	5.9	6.2
	S.E.C.	7.0	11.4	16.3	22.3	22.5	21.8	29.4
MECHANICAL ANALYSES								
% Sand	S	34**	31**	28**	24	22	26	30
% Silt	Si	55**	45**	35**	34	32	33	32
% Clay	C	11**	24**	37**	42	46	41	38
% Fine Clay	FC	3**	10**	17**	28	27	21	18
Si/C		5.0	2.4	2.2	1.5	1.7	1.9	2.1
FC/CC		0.38	0.71	0.85	2.00	1.42	1.05	0.90

* Mean of 3 replicates ** Mean of 2 replicates
† pH determined using 0.01 M $CaCl_2$ soil suspension

SITE 3
PEDON 1

Horizon		Ah	Ae	AB	Bt_1	Bt_2	Bt_3	BC	C
Depth (in.)		0-2	2-4.5	4.5-9	9-15	15-22	22-31	31-39	39 +
PHYSICAL ANALYSES									
Moisture Content % Dry Wt.		-	30.7*	-	25.5*	23.0*	24.9*	-	23.2*
Bulk Density gm/cc		-	1.23*	-	1.48*	1.51*	1.53*	-	1.56*
Corr. Bulk Density gm/cc		-	1.22*	-	1.47*	1.50*	1.53*	-	1.55*
Mean Deviation Corr. Bulk Density		-	0.05	-	0.03	0.02	0.02	-	0.01
CHEMICAL ANALYSES									
pH†		5.5	5.2	5.0	4.4	4.2	4.2	4.2	4.8
% Total Carbon		4.78	0.72	0.81	0.56	0.65	0.60	0.52	0.46
% Nitrogen		0.41	0.07	0.07	0.05	0.04	0.04	0.04	0.03
C/N		11.7	10.3	11.6	11.2	16.3	15.0	13.0	15.3
Exchange	H	7.4	2.0	3.2	4.7	5.6	5.8	5.3	2.6
Analyses	Na	0.1	0.0	0.0	0.1	0.2	0.1	0.2	0.2
(meq/100 gm)	K	1.2	0.6	0.7	0.5	0.5	0.4	0.4	0.4
	Ca	14.4	6.0	15.6	14.6	14.1	9.5	13.9	14.7
	Mg	2.2	1.7	5.6	5.9	6.2	4.3	6.4	7.0
	S.E.C.	25.3	10.3	25.1	25.8	26.6	20.1	26.2	24.9
MECHANICAL ANALYSES									
% Sand	S	31	36	26	30	28	28	31	30
% Silt	Si	55	46	31	24	28	31	29	30
% Clay	C	14	18	43	46	44	41	40	40
% Fine Clay	FC	7	5	22	26	25	35	33	33
Si/C		3.9	2.6	0.7	0.5	0.6	0.8	0.7	0.8
FC/CC		1.00	0.38	1.05	1.30	1.32	5.83	4.72	4.72

* Mean of 3 replicates
† pH determined using 0.01 M $CaCl_2$ soil suspension

SITE 3
PEDON 2

Horizon		Ah	Ae	AB	Bt_1	Bt_2	Bt_3	BC	C
Depth (in.)		0-1.5	1.5-5	5-9.5	9.5-15	15-23	23-31	31-40	40 +
PHYSICAL ANALYSES									
Moisture Content % Dry Wt.		-	20.1*	-	24.2*	24.2*	22.0*	-	19.8*
Bulk Density gm/cc		-	1.34*	-	1.49*	1.54*	1.58*	-	1.62*
Corr. Bulk Density gm/cc		-	1.33*	-	1.48*	1.54*	1.56*	-	1.61*
Mean Deviation Corr. Bulk Density		-	0.07	-	0.02	0.04	0.03	-	0.01
CHEMICAL ANALYSES									
pH †		4.7	4.2	5.0	4.8	4.3	4.3	4.3	5.2
% Total Carbon		5.95	0.57	0.74	0.66	0.51	0.50	0.40	0.50
% Nitrogen		0.47	0.06	0.07	0.05	0.04	0.04	0.03	0.03
C/N		12.7	9.5	10.6	13.2	12.8	12.5	13.3	16.7
Exchange	H	12.7	2.8	2.4	3.2	4.8	5.0	4.5	2.0
Analyses	Na	0.0	0.0	0.1	0.1	0.2	0.2	0.2	0.1
(meq/100 gm)	K	1.7	0.2	0.5	0.6	0.6	0.5	0.4	0.3
	Ca	9.6	3.4	11.4	14.9	14.7	14.4	13.3	6.1
	Mg	2.5	0.8	4.0	6.1	6.5	6.7	6.4	3.0
	S.E.C.	26.5	7.2	18.4	24.9	26.8	26.8	24.8	11.5
MECHANICAL ANALYSES									
% Sand	S	22	35	30	25	24	25	27	30
% Silt	Si	54	58	37	30	30	30	31	30
% Clay	C	24	7	33	44	46	45	43	40
% Fine Clay	FC	11	2	27	35	39	35	33	33
Si/C		2.3	8.3	1.1	0.7	0.7	0.7	0.7	0.8
FC/CC		0.85	0.40	4.50	3.89	5.57	3.50	3.30	4.72

* Mean of 3 replicates
† pH determined using 0.01 M $CaCl_2$ soil suspension

SITE 3
PEDON 3

Horizon		Ah	Ae	AB	Bt_1	Bt_2	Bt_3	BC	C
Depth (in.)		0-1.5	1.5-5	5-9	9-15	15-22	22-31	31-38	38 +
PHYSICAL ANALYSES									
Moisture Content % Dry Wt.		-	23.6*	-	22.1*	20.0*	20.2*	-	22.3*
Bulk Density gm/cc		-	1.28*	-	1.54*	1.62*	1.61*	-	1.61*
Corr. Bulk Density gm/cc		-	1.27*	-	1.54*	1.61*	1.60*	-	1.60*
Mean Deviation Corr. Bulk Density		-	0.03	-	0.02	0.04	0.01	-	0.00
CHEMICAL ANALYSES									
pH †		6.4	6.5	6.2	6.0	4.9	4.6	4.5	5.1
% Total Carbon		4.19	0.84	0.69	0.60	0.55	0.51	0.53	0.50
% Nitrogen		0.33	0.07	0.06	0.05	0.04	0.04	0.04	0.03
C/N		12.7	12.0	11.5	12.0	13.8	12.8	13.3	16.7
Exchange	H	1.4	0.8	1.2	1.5	2.9	3.6	4.0	2.3
Analyses	Na	0.0	0.0	0.0	0.1	0.1	0.1	0.2	0.2
(meq/100 gm)	K	1.2	0.5	0.6	0.7	0.7	0.5	0.5	0.4
	Ca	33.9	19.7	27.3	28.9	27.9	26.2	27.6	27.9
	Mg	1.7	2.4	5.1	6.4	6.2	5.9	5.9	6.5
	S.E.C.	38.2	23.4	34.2	37.6	37.8	36.3	38.2	37.3
MECHANICAL ANALYSES									
% Sand	S	30	30	32	28	27	28	28	26
% Silt	Si	52	42	30	30	28	30	30	31
% Clay	C	18	28	38	42	45	42	42	43
% Fine Clay	FC	6	10	19	24	25	24	24	21
Si/C		2.9	1.5	0.8	0.7	0.6	0.7	0.7	0.7
FC/CC		0.50	0.56	1.00	1.33	1.25	1.33	1.33	0.95

* Mean of 3 replicates
† pH determined using 0.01 M $CaCl_2$ soil suspension

SITE 3
PEDON 4

Horizon		Ah	Ae	AB	Bt_1	Bt_2	Bt_3	BC	C
Depth (in.)		0-1	1-6	6-8.5	8.5-16	16-26	26-32	32-40	40 +
PHYSICAL ANALYSES									
Moisture Content % Dry Wt.		-	20.7*	-	22.6*	23.0*	19.9*	-	22.3*
Bulk Density gm/cc		-	1.50*	-	1.50*	1.51*	1.66*	-	1.59*
Corr. Bulk Density gm/cc		-	1.48*	-	1.49*	1.49*	1.65*	-	1.57*
Mean Deviation Corr. Bulk Density		-	0.09	-	0.00	0.03	0.03	-	0.02
CHEMICAL ANALYSES									
pH†		5.1	5.2	5.5	5.2	4.7	4.5	4.5	5.8
% Total Carbon		5.38	0.62	0.35	0.50	0.54	0.51	0.51	0.54
% Nitrogen		0.47	0.05	0.04	0.05	0.05	0.04	0.04	0.04
C/N		11.4	12.4	8.8	10.0	10.8	12.8	12.8	13.5
Exchange	H	10.0	1.5	1.3	2.1	3.1	4.0	3.7	1.3
Analyses	Na	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.1
(meq/100 gm)	K	1.7	0.3	0.5	0.8	0.9	0.8	0.7	0.6
	Ca	25.8	4.7	13.9	22.1	24.9	22.6	21.4	25.2
	Mg	2.0	0.7	3.2	5.3	6.2	5.7	5.6	6.2
	S.E.C.	39.5	7.2	18.9	30.4	35.2	33.2	31.5	33.4
MECHANICAL ANALYSES									
% Sand	S	26	45	41	34	24	26**	27**	28**
% Silt	Si	50	49	34	31	31	30**	30**	31**
% Clay	C	24	6	25	35	45	44**	43**	41**
% Fine Clay	FC	11	3	10	18	29	28**	25**	24**
Si/C		2.1	2.0	2.5	2.0	1.6	1.6	1.7	1.7
FC/CC		0.85	1.00	0.67	1.06	1.81	1.75	1.39	1.41

* Mean of 3 replicates ** Mean of 2 replicates
† pH determined using 0.01 M $CaCl_2$ soil suspension

SITE 3
PEDON 5

Horizon		Ah	Aegj	ABgj	Btgj1	Btgj2	Btgj3	BCgj	Cg
Depth (in.)		0-2	2-6	6-9	9-16	16-25	25-33	33-41	41 +
PHYSICAL ANALYSES									
Moisture Content % Dry Wt.		-	21.5*	-	25.0*	24.7*	24.3*	-	26.8*
Bulk Density gm/cc		-	1.49*	-	1.51*	1.47*	1.50*	-	1.46*
Corr. Bulk Density gm/cc		-	1.47*	-	1.51*	1.46*	1.48*	-	1.45*
Mean Deviation Corr. Bulk Density		-	0.03	-	0.03	0.04	0.06	-	0.10
CHEMICAL ANALYSES									
pH †		4.4	4.4	4.8	4.5	4.3	4.2	4.3	4.5
% Total Carbon		9.63	0.60	0.62	0.61	0.59	0.58	0.53	0.51
% Nitrogen		0.72	0.06	0.05	0.05	0.04	0.04	0.04	0.04
C/N		13.4	10.0	12.4	12.2	14.8	14.5	13.3	12.8
Exchange	H	20.1	2.6	3.1	4.1	5.0	5.4	5.0	3.9
Analyses	Na	0.1	0.0	0.1	0.1	0.2	0.2	0.2	0.2
(meq/100 gm)	K	0.2	0.3	0.4	0.5	0.6	0.5	0.4	0.5
	Ca	30.7	3.8	16.2	19.1	20.6	18.3	18.5	22.0
	Mg	2.4	0.6	3.5	4.8	5.4	6.2	6.1	7.3
	S.E.C.	53.5	7.3	23.3	28.6	31.8	30.6	30.2	33.9
MECHANICAL ANALYSES									
% Sand	S	21	31**	28**	27**	26**	28**	28**	27
% Silt	Si	46	59**	34**	30**	29**	30**	31**	31
% Clay	C	33	10**	38**	43**	45**	42**	41**	42
% Fine Clay	FC	16	4**	22**	27**	29**	27**	27**	26
Si/C		1.4	5.9	0.9	0.7	0.6	0.7	0.8	0.7
FC/CC		0.94	0.67	1.37	1.69	1.81	1.80	1.93	1.62

* Mean of 3 replicates ** Mean of 2 replicates
† pH determined using 0.01 M $CaCl_2$ soil suspension

APPENDIX C

Modal Analysis

INDEX TO SAMPLE NO.

First integer: 1 refers to Site 1 (S9-TP49-R25-W5)
2 refers to Site 2 (NE5-TP52-R13-W5)
3 refers to Site 3 (NW3-TP61-R13-W5)

Second integer: refers to pedon sampled. Pedon locations at sampling sites are presented on pages 25, 26 and 27 of the Materials and Methods section for Sites 1, 2 and 3, respectively.

Third integer: 1 and 2* refer to upper and lower portions of Bt_1 horizons, respectively.

3* and 4 refer to upper and lower portions of Bt_2 horizons, respectively.

5 and 6 refer to upper and lower portions of Bt_3 horizons, respectively.

* Pedon 1 at Site 1 is an exception to the index as the central portion of the Bt was sampled and indexed 1-1-2, and the lower portion indexed 1-1-3.

NOTE: The use of the letter "R" following the numerical index is indicative of the use of the replicate of the duplicate samples for modal analysis.

Sample No.	Primary Minerals	Rock Fragments	Ortho Vughs	Meta Vughs	Planes	Other (voids)	Plasma Around Skeleton	Random Plasma	Other Plasma	Plane Cutan	Vugh Cutan	Other Cutan	OrganicMatter
1-1-1	14	5	1	22	1	0	14	31	8	0	1	3	0
1-1-1	16	4	2	21	2	0	20	34	1	0	0	0	0
1-1-1	11	8	0	9	3	1	19	43	3	0	0	0	3
1-1-1	6	14	2	18	1	2	19	30	8	0	0	0	0
1-1-2	11	19	1	14	5	1	18	20	7	1	0	3	0
1-1-2	13	12	1	9	9	7	14	22	8	1	2	2	0
1-1-2	12	9	0	12	10	4	15	22	9	3	3	1	0
1-1-2	10	9	0	10	2	1	17	33	10	3	3	1	0
1-1-3	8	39	0	11	6	0	15	9	5	0	3	4	0
1-1-3	9	26	0	18	9	1	13	12	7	3	2	0	0
1-1-3	16	21	1	14	3	0	8	24	6	4	0	3	0
1-1-3	14	20	1	10	8	2	13	22	5	1	0	4	0
1-2-1	12	15	2	4	2	3	11	41	3	2	3	2	0
1-2-1	16	11	3	16	5	3	8	28	5	2	0	0	3
1-2-1	13	19	0	7	3	2	10	28	7	0	4	5	2
1-2-1	11	16	2	10	6	2	9	28	8	2	2	4	0
1-2-2	13	10	0	5	9	3	14	32	7	1	5	1	0
1-2-2	10	26	0	6	7	4	13	25	3	0	3	3	0
1-2-2	8	27	0	17	9	0	9	18	3	0	4	5	0
1-2-2	8	24	1	5	11	0	17	27	2	3	1	1	0
1-3-1R	9	24	1	4	1	2	18	34	4	0	1	2	0
1-3-1R	12	25	0	2	3	4	12	31	5	1	2	3	0
1-3-1R	13	27	1	0	0	3	13	36	4	0	1	2	0
1-3-1R	8	48	0	6	3	1	12	14	6	1	0	1	0
1-3-2R	12	19	0	1	0	7	20	34	3	2	1	1	0
1-3-2R	14	21	2	3	3	0	20	27	5	0	2	3	0
1-3-2R	16	24	0	2	7	3	18	19	7	0	1	3	0
1-3-2R	7	32	2	2	6	1	20	19	5	3	0	3	0
1-4-1	10	37	0	6	5	5	16	15	4	1	0	1	0
1-4-1	5	34	0	13	9	2	7	13	10	2	3	2	0
1-4-1	12	25	1	9	6	3	15	18	8	2	0	1	0
1-4-1	10	22	0	16	4	4	13	22	7	0	2	0	0
1-4-2	11	22	5	9	5	4	19	15	6	2	1	1	0
1-4-2	10	26	0	7	3	6	16	16	7	5	2	2	0
1-4-2	16	33	1	2	1	6	17	16	3	1	0	4	0
1-4-2	5	36	1	8	0	8	12	16	10	0	0	2	2
1-5-1	10	27	0	4	13	14	7	10	9	3	3	0	0
1-5-1	8	17	1	2	9	10	19	17	9	3	3	2	0
1-5-1	2	26	0	5	12	9	14	17	9	2	1	2	1
1-5-1	8	16	0	10	10	1	16	18	13	3	1	0	4
1-5-2	10	44	0	1	2	6	14	14	4	0	3	1	1
1-5-2	9	39	0	4	2	11	12	16	5	0	1	1	0
1-5-2	6	38	0	1	4	8	15	13	6	6	0	3	0
1-5-2	6	28	1	3	3	10	18	23	6	0	1	0	1

Sample No.	Primary Minerals	Rock Fragments	Ortho Vughs	Meta Vughs	Planes	Other (voids)	Plasma Around Skeleton	Random Plasma	Other Plasma	Plane Cutan	Vugh Cutan	Other Cutan	Organic Matter
2-1-1	14	16	0	6	13	9	15	16	9	2	0	0	0 *
2-1-1	23	9	1	5	2	3	18	28	11	0	0	0	0 *
2-1-1	22	14	1	3	3	14	20	17	6	0	0	0	0 *
2-1-1	18	16	0	5	12	6	15	15	10	2	1	0	0 *
2-1-2	18	19	0	1	2	5	30	15	7	1	2	0	0 *
2-1-2	16	23	0	0	1	9	22	21	6	1	0	1	0 *
2-1-2	25	11	0	1	0	7	14	31	9	0	0	2	0
2-1-2	17	11	0	0	4	4	26	29	5	1	0	3	0
2-1-3	17	12	0	1	12	3	16	23	10	3	2	0	1
2-1-3	15	9	0	0	9	4	21	21	10	6	4	0	1
2-1-3	17	9	0	1	7	6	12	28	16	1	3	0	0
2-1-3	19	19	0	2	5	7	12	18	13	2	2	1	0
2-1-4	20	19	1	0	0	6	17	27	9	0	0	0	1
2-1-4	17	14	0	4	2	3	16	24	14	0	1	3	2
2-1-4	19	10	0	3	3	6	17	24	17	0	0	1	0
2-1-4	18	16	0	1	1	3	21	25	13	0	0	2	0
2-2-1R	26	11	0	0	3	8	14	21	15	1	0	1	0
2-2-1R	22	8	0	3	1	8	24	22	10	1	0	1	0
2-2-1R	24	12	1	3	1	7	13	21	16	0	2	0	0
2-2-1R	16	12	0	0	7	6	19	20	15	0	3	2	0
2-2-2	24	6	0	4	3	8	15	23	16	0	0	1	0
2-2-2	31	7	0	0	3	9	20	20	8	2	0	0	0
2-2-2	28	7	0	2	5	6	18	14	17	1	2	0	0
2-2-2	27	11	0	4	2	6	21	14	11	4	0	0	0
2-2-3	19	23	0	3	5	5	16	20	8	0	1	0	0
2-2-3	16	19	0	4	9	7	17	14	10	2	1	1	0
2-2-3	12	15	2	3	6	7	21	18	11	1	2	0	2
2-2-3	15	16	0	1	5	5	19	25	10	2	0	1	1
2-2-4R	15	16	0	3	3	9	21	17	12	2	0	1	1
2-2-4R	15	13	0	0	1	19	16	10	12	2	2	2	8
2-2-4R	17	17	0	0	3	7	19	14	22	1	0	0	0
2-2-4R	23	14	0	3	3	3	18	20	12	2	1	0	1
2-3-1	13	10	0	8	4	3	14	32	16	0	0	0	0
2-3-1	23	8	2	1	0	4	17	33	12	0	0	0	0
2-3-1	14	9	0	2	2	8	14	28	20	2	0	0	1
2-3-1	15	8	0	7	3	7	23	26	11	0	0	0	0
2-3-2	14	4	0	1	2	6	21	25	17	2	0	1	7
2-3-2	14	8	0	0	1	11	22	20	15	0	0	0	9
2-3-2	17	9	0	0	3	11	21	25	8	2	0	0	4
2-3-2	17	5	0	0	2	7	21	25	17	1	0	0	5
2-3-3	9	11	0	3	4	4	20	24	16	6	1	2	0
2-3-3	14	19	0	0	0	4	22	25	10	5	0	1	0
2-3-3	15	14	0	0	4	5	21	21	12	8	0	0	0
2-3-3	21	15	0	1	5	3	24	17	11	2	0	1	0

Sample No.	Primary Minerals	Rock Fragments	Ortho Vughs	Meta Vughs	Planes	Other (voids)	Plasma Around Skeleton	Random Plasma	Other Plasma	Plane Cutan	Vugh Cutan	Other Cutan	Organic Matter
2-3-4R	36	8	0	2	6	4	18	13	8	1	4	0	0
2-3-4R	26	10	1	2	3	9	20	15	9	2	1	2	0
2-3-4R	21	24	0	0	1	2	24	14	9	2	3	0	0
2-3-4R	23	9	0	7	8	3	17	18	11	2	1	1	0
2-4-1	22	1	0	1	6	1	20	34	12	1	1	1	0
2-4-1	25	7	0	0	8	4	18	25	11	2	0	0	0
2-4-1	27	6	0	1	6	2	17	28	12	1	0	0	0
2-4-1	20	4	0	4	3	5	14	34	13	2	1	0	0
2-4-2R	13	14	0	4	7	6	17	19	14	3	2	0	1
2-4-2R	13	26	0	7	3	6	14	21	6	2	2	0	0
2-4-2R	16	23	0	4	1	5	20	23	7	0	0	0	1
2-4-2R	18	21	0	2	5	4	16	22	10	1	1	0	0
2-4-3	9	18	0	1	14	1	16	23	12	3	1	0	2
2-4-3	14	5	1	3	4	7	15	36	13	2	0	0	0
2-4-3	12	18	0	0	4	3	22	22	17	1	1	0	0
2-4-3	13	12	0	0	6	2	25	25	15	2	0	0	0
2-4-4R	20	5	0	5	4	2	21	25	12	2	1	0	3
2-4-4R	18	8	0	0	11	3	23	19	15	1	0	0	2
2-4-4R	16	3	0	3	9	1	27	23	16	1	0	0	1
2-4-4R	14	8	2	1	6	5	25	21	15	3	0	0	0
2-5-1R	14	4	0	0	5	3	24	30	16	4	0	0	0
2-5-1R	19	7	2	3	4	2	18	25	14	4	2	0	0
2-5-1R	9	8	2	7	6	3	19	27	10	6	2	1	0
2-5-1R	20	17	0	1	4	2	21	20	10	4	0	1	0
2-5-2R	13	5	1	0	7	3	19	30	13	8	1	0	0
2-5-2R	21	14	0	7	2	5	15	11	12	12	0	0	1
2-5-2R	13	6	0	8	4	2	23	25	11	5	2	0	1
2-5-2R	11	7	0	3	3	6	20	21	14	8	4	3	0
2-5-3	21	3	0	4	5	3	21	23	14	4	2	0	0
2-5-3	27	5	0	2	2	1	24	21	13	3	1	1	0
2-5-3	24	3	0	2	2	3	26	16	18	3	2	1	0
2-5-3	19	10	0	1	2	1	24	26	12	3	2	0	0
2-5-4	13	7	11	2	0	4	19	14	25	2	2	0	1
2-5-4	21	10	2	5	1	1	22	10	24	0	4	0	0
2-5-4	30	7	2	0	1	6	24	8	15	3	3	0	1
2-5-4	25	8	1	2	2	3	20	11	26	0	1	1	0

Sample No.	Primary Minerals	Rock Fragments	Ortho Vughs	Meta Vughs	Planes	Other (voids)	Plasma Around Skeleton	Random Plasma	Other Plasma	Plane Cutan	Vugh Cutan	Other Cutan	Organic Matter
3-1-1R	20	14	2	1	10	2	24	12	10	3	1	1	0
3-1-1R	21	21	0	6	9	1	19	8	11	2	2	0	0
3-1-1R	13	9	0	4	17	7	14	12	13	2	2	0	7
3-1-1R	13	19	1	2	9	7	19	13	11	1	2	0	3
3-1-2	17	19	0	3	14	1	18	19	8	0	0	1	0
3-1-2	12	18	0	0	9	13	20	12	10	4	0	0	2
3-1-2	21	10	0	0	13	14	16	12	11	0	1	1	1
3-1-2	17	14	0	0	17	17	19	6	7	2	0	0	1
3-1-3	20	16	0	1	11	4	21	12	12	1	1	1	0
3-1-3	16	10	0	0	24	2	20	14	9	4	1	0	0
3-1-3	27	10	0	4	4	6	23	12	14	0	0	0	0
3-1-3	24	23	2	1	4	2	22	7	14	0	1	0	0
3-1-4	19	7	0	8	12	3	21	13	6	7	4	0	0
3-1-4	20	10	0	1	9	2	21	13	15	6	2	1	0
3-1-4	13	10	0	4	14	7	21	13	12	2	2	2	0
3-1-4	16	23	0	5	5	7	23	11	8	1	1	0	0
3-1-5	24	9	0	3	10	4	18	11	15	5	1	0	0
3-1-5	25	15	0	2	6	2	27	6	15	2	0	0	0
3-1-5	15	13	0	9	15	3	20	9	13	1	2	0	0
3-1-5	22	24	0	1	3	2	26	11	9	1	1	0	0
3-1-6	15	24	0	4	2	4	25	9	12	2	2	1	0
3-1-6	18	19	0	5	8	6	21	11	7	2	3	0	0
3-1-6	24	12	0	6	3	6	28	7	11	2	1	0	0
3-1-6	14	16	0	0	5	7	29	11	11	1	2	3	1
3-2-1R	15	21	0	2	6	3	17	15	18	0	2	0	1
3-2-1R	11	16	0	1	13	6	25	11	17	0	0	0	0
3-2-1R	15	15	0	0	15	4	16	14	17	1	0	3	0
3-2-1R	11	18	0	1	6	4	24	12	20	1	1	2	0
3-2-2	19	14	0	3	7	3	26	9	17	0	2	0	0
3-2-2	23	17	0	3	8	2	19	8	15	3	2	0	0
3-2-2	15	7	0	0	7	15	21	12	14	2	0	1	6
3-2-2	19	17	0	1	5	4	23	15	14	1	1	0	0
3-2-3R	16	16	0	2	8	3	22	12	17	2	1	1	0
3-2-3R	19	17	0	6	3	2	22	15	15	0	1	0	0
3-2-3R	24	18	0	2	11	1	19	6	15	3	0	1	0
3-2-3R	19	18	0	2	7	5	23	7	9	6	3	1	0
3-2-4	14	33	0	8	5	4	18	5	10	1	2	0	0
3-2-4	20	31	0	4	4	3	20	9	8	0	1	0	0
3-2-4	22	34	0	2	3	2	20	7	7	2	1	0	0
3-2-4	22	12	0	2	5	4	22	9	18	4	1	0	1
3-2-5	16	17	0	9	7	5	16	8	14	3	4	1	0
3-2-5	20	17	0	0	7	2	22	12	17	2	0	1	0
3-2-5	23	13	0	2	4	2	18	12	17	1	4	0	4
3-2-5	13	20	0	11	5	3	19	13	14	0	2	0	0

Sample No.	Primary Minerals	Rock Fragments	Ortho Vughs	Meta Vughs	Planes	Other (voids)	Plasma Around Skeleton	Random Plasma	Other Plasma	Plane Cutan	Vugh Cutan	Other Cutan	Organic Matter
3-2-6	26	16	0	2	8	5	17	13	11	1	1	0	0
3-2-6	22	21	0	4	7	5	17	8	10	2	3	0	1
3-2-6	20	11	0	7	2	4	24	10	17	1	4	0	0
3-2-6	21	13	0	9	5	5	18	15	12	0	1	1	0
3-3-1	9	27	0	1	19	2	19	11	8	3	0	1	0
3-3-1	18	17	3	3	7	2	16	17	9	6	1	1	0
3-3-1	14	16	0	4	9	5	20	14	15	3	0	0	0
3-3-1	10	17	0	6	7	21	17	7	7	1	0	0	7
3-3-2R	24	19	0	6	4	1	17	13	8	0	4	1	3
3-3-2R	15	21	0	6	11	3	22	7	12	2	1	0	0
3-3-2R	15	23	0	3	5	1	24	13	13	1	2	0	0
3-3-2R	13	16	0	6	3	3	23	16	12	1	7	0	0
3-3-3	18	22	0	2	1	1	22	10	15	6	1	1	1
3-3-3	21	21	0	3	6	2	20	10	10	3	1	3	0
3-3-3	16	19	0	1	6	4	20	9	13	6	0	0	6
3-3-3	14	21	0	0	4	4	24	14	11	5	0	0	3
3-3-4R	11	25	0	8	5	3	19	11	11	5	2	0	0
3-3-4R	13	23	0	2	6	4	23	11	5	5	5	3	0
3-3-4R	17	19	0	0	7	10	16	11	16	3	0	1	0
3-3-4R	16	16	0	1	10	1	22	9	16	7	0	1	1
3-3-5	20	19	0	4	14	5	16	11	7	0	2	2	0
3-3-5	19	26	0	0	5	4	19	15	8	2	0	2	0
3-3-5	20	29	0	5	4	4	19	12	6	0	1	0	0
3-3-5	19	18	0	4	7	3	14	21	9	1	4	0	0
3-3-6R	20	10	0	1	2	8	17	28	13	1	0	0	0
3-3-6R	23	14	0	6	4	3	17	17	9	1	2	1	3
3-3-6R	21	28	0	3	1	6	16	16	5	0	1	1	2
3-3-6R	14	27	0	1	2	8	22	16	6	0	3	1	0
3-4-1R	15	13	0	5	20	4	16	14	13	0	0	0	0
3-4-1R	18	15	0	2	8	6	20	15	13	0	0	0	3
3-4-1R	15	8	0	10	10	2	24	20	10	0	0	0	1
3-4-1R	21	14	0	2	7	2	18	23	12	0	1	0	0
3-4-2R	15	14	0	2	16	4	17	16	16	0	0	0	0
3-4-2R	20	12	0	4	9	0	18	19	14	0	1	0	3
3-4-2R	18	22	0	1	12	7	19	8	10	0	0	0	4
3-4-2R	22	14	0	8	11	4	23	11	7	0	0	0	0
3-4-3	19	29	0	4	2	6	16	9	13	1	1	0	0
3-4-3	20	13	0	4	5	5	25	11	11	3	3	0	0
3-4-3	19	13	0	4	8	3	19	13	18	1	1	1	0
3-4-3	20	11	0	6	1	6	21	11	16	3	4	1	0
3-4-4R	23	19	0	5	2	5	21	9	12	1	3	0	0
3-4-4R	19	14	0	3	5	5	26	12	14	1	1	0	0
3-4-4R	18	6	0	0	29	1	19	8	17	2	0	0	0
3-4-4R	16	12	0	5	6	4	25	17	11	1	3	0	0

Sample No.	Primary Minerals	Rock Fragments	Ortho Vughs	Meta Vughs	Planes	Other (voids)	Plasma Around Skeleton	Random Plasma	Other Plasma	Plane Cutan	Vugh Cutan	Other Cutan	Organic Matter
3-4-5	28	17	0	2	8	4	18	10	9	3	1	0	0
3-4-5	17	26	0	5	7	5	17	11	8	1	2	1	0
3-4-5	30	19	0	3	10	4	14	10	10	0	0	0	0
3-4-5	14	18	0	9	19	6	13	9	12	0	0	0	0
3-4-6R	16	21	0	6	2	3	16	14	11	0	9	0	2
3-4-6R	18	21	0	1	4	5	23	11	14	0	2	0	1
3-4-6R	17	12	0	1	8	3	26	15	10	6	2	0	0
3-4-6R	18	23	0	1	10	6	21	6	12	3	0	0	0
3-5-1	19	21	0	1	18	6	13	8	11	0	0	1	2
3-5-1	13	9	0	1	11	16	12	14	20	0	2	2	0
3-5-1	21	14	0	2	16	7	18	7	11	1	0	0	3
3-5-1	18	12	3	0	16	4	19	9	16	1	0	0	2
3-5-2	19	8	0	7	6	3	21	22	11	3	0	0	0
3-5-2	25	9	0	1	9	3	18	10	18	4	2	1	0
3-5-2	18	17	0	0	11	5	21	9	16	1	1	1	0
3-5-2	21	11	0	4	4	2	19	13	19	2	5	0	0
3-5-3	19	9	0	4	4	7	23	13	17	2	1	1	0
3-5-3	24	10	0	5	2	3	16	15	16	3	5	1	0
3-5-3	17	23	0	10	2	2	19	10	15	0	1	1	0
3-5-3	18	19	0	5	1	4	15	8	17	8	5	0	0
3-5-4	14	25	0	3	4	9	18	14	10	2	0	0	1
3-5-4	16	9	0	4	15	5	14	10	17	2	4	0	4
3-5-4	22	6	0	3	3	6	21	19	15	2	2	1	0
3-5-4	20	10	0	11	12	4	18	8	14	0	2	0	1
3-5-5R	20	18	0	1	5	3	21	11	15	5	0	1	0
3-5-5R	13	19	0	3	3	3	23	14	12	2	4	4	0
3-5-5R	20	15	0	6	3	4	23	10	15	0	3	1	0
3-5-5R	16	22	0	3	1	2	20	12	23	1	0	0	0
3-5-6	20	17	1	3	5	8	12	17	16	0	0	1	0
3-5-6	17	17	1	2	5	9	14	16	18	0	1	0	0
3-5-6	22	29	0	4	3	3	16	12	9	0	2	0	0
3-5-6	18	28	1	1	5	11	6	19	10	0	1	0	0